

ME571/Geol571 Advanced Topics  
Geology and Economics of Strategic  
and Critical Minerals  
SPRING 2015

BASIC CONCEPTS: GEOLOGY,  
MINING, AND PROCESSING OF  
STRATEGIC AND CRITICAL  
MINERALS

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# OUTLINE

- Definitions
- Classification of mineral resources on U.S. federal land
- Life cycle of a mine
- Classification of reserves and resources
- Geology of industrial minerals deposits
  - Types of mineral deposits
  - Geoenvironmental Models (GEMs)
- Field notes
- Sampling
- Data verification

# DEFINITIONS

A **mineral occurrence** is any locality where a useful mineral or material is found.

A **mineral prospect** is any occurrence that has been developed by underground or by above ground techniques, or by subsurface drilling to determine the extent of mineralization.

The terms **mineral**  
**occurrence** and **mineral**  
**prospect** do not have any  
resource or economic  
implications.

A **mineral deposit** is any occurrence of a valuable commodity or mineral that is of sufficient size and grade (concentration) that has potential for economic development under past, present, or future favorable conditions.

An **ore deposit** is a well-defined mineral deposit that has been tested and found to be of sufficient size, grade, and accessibility to be extracted (i.e. mined) and processed at a profit at a specific time. Thus, the size and grade of an ore deposit changes as the economic conditions change. **Ore refers to industrial minerals as well as metals.**



# *Mineral Deposits versus Ore Bodies*

mineral deposit  $\neq$  ore body

ore body = reserves

mineral deposit =  $\pm$  reserves  
+ unmineable  
+ uneconomic  
+ mined



**Gangue – the unwanted part of the ore, comprises minerals such as calcite, quartz and iron pyrite**







**Grade – Refers to the proportion of the ore that is the ore mineral or actual elemental metal content that can be extracted from it - expressed as a percentage**

**The grade of the Cornish tin ore is between 0.5 and 1.5 % cassiterite ( $\text{Sn O}_2$ ) This means there is between 98.5 and 99.5% gangue in the ore**

**Tenor – Refers to the percentage of the ore mineral that is actual metal to be extracted**



**The tenor of iron ores vary considerably:  
Limonite 35% Fe, Haematite 57% Fe, Magnetite 70%**

# Calculating Ore Grade as % Mineral Content and % Elemental Metal Content

Using Chalcopyrite as an example:

Chemical Formula is  $\text{Cu, Fe, S}_2$

Relative atomic masses are:

$\text{Cu} = 63.5$ ,  $\text{Fe} = 56$  and  $\text{S} = 32$

So 1kg of copper will be found in:

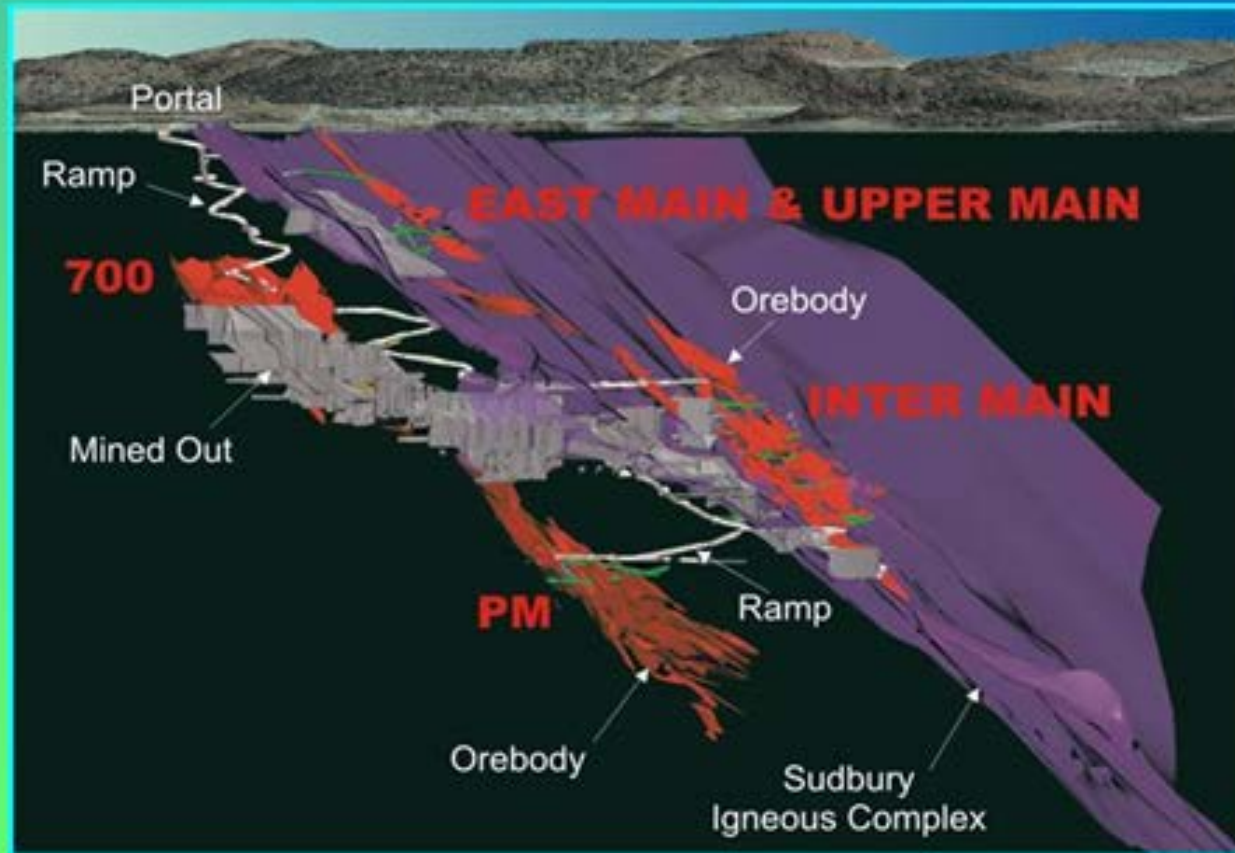
$$63.5 + 56 + (2 \times 32)/63.5$$

This equals 2.9 kg of Chalcopyrite

If the ore contained 2% copper then it would have  $2 \times 2.9 = 5.8\%$  Chalcopyrite



**Tonnage – Refers to the total amount of metal that can be extracted from any particular ore deposit.**



**Tonnage is calculated by taking into account the volume of the ore deposit, the grade of the ore and the tenor of the ore mineral**

# **CLASSIFICATION OF MINERAL RESOURCES ON U.S. FEDERAL LAND**

**Locatable Minerals** are whatever is recognized as a valuable mineral by standard authorities, whether metallic or other substance, when found on public land open to mineral entry in quality and quantity sufficient to render a claim valuable on account of the mineral content, under the United States Mining Law of 1872. Specifically excluded from location are the leasable minerals, common varieties, and salable minerals.



**Leasable Minerals** The passage of the Mineral Leasing Act of 1920, as amended from time to time, places the following minerals under the leasing law: oil, gas, coal, oil shale, sodium, potassium, phosphate, native asphalt, solid or semisolid bitumen, bituminous rock, oil-impregnated rock or sand, and sulfur in Louisiana and New Mexico.

**Salable Minerals** The Materials Act of 1947, as amended, removes petrified wood, common varieties of sand, stone, gravel, pumice, pumicite, cinders, and some clay from location and leasing. These materials may be acquired by purchase only.

# Other terms



# Canadian Instrument 43-101

- Set of rules and guidelines for reporting information relating to a mineral property in order to present these results to the Canadian stock exchange
  - created after the Bre-X scandal to protect investors from unsubstantiated mineral project disclosures
  - gold reserves at (Bre-X's) Busang were alleged to be 200 million ounces (6,200 t), or up to 8% of the entire world's gold reserves
- FRAUD
- Similar to JORC (joint ore reserves committee code, Australia)
- South African Code for the Reporting of Mineral Resources and Mineral Reserves (SAMREC)

# Other terms

- Adjacent property
  - Company has no interest
  - Boundary close to project
  - Geologic characteristics similar to project
- Advanced property
  - Mineral reserves
  - Minerals resources with a PEA or feasibility study
- Early stage exploration property

# Qualified person (43-101)

- engineer/geoscientist with a university degree, or equivalent accreditation, in an area of geoscience, or engineering, relating to mineral exploration or mining
- has at least five years of experience
- has experience relevant to the subject matter of the mineral project and the technical report
- is in good standing with a professional association

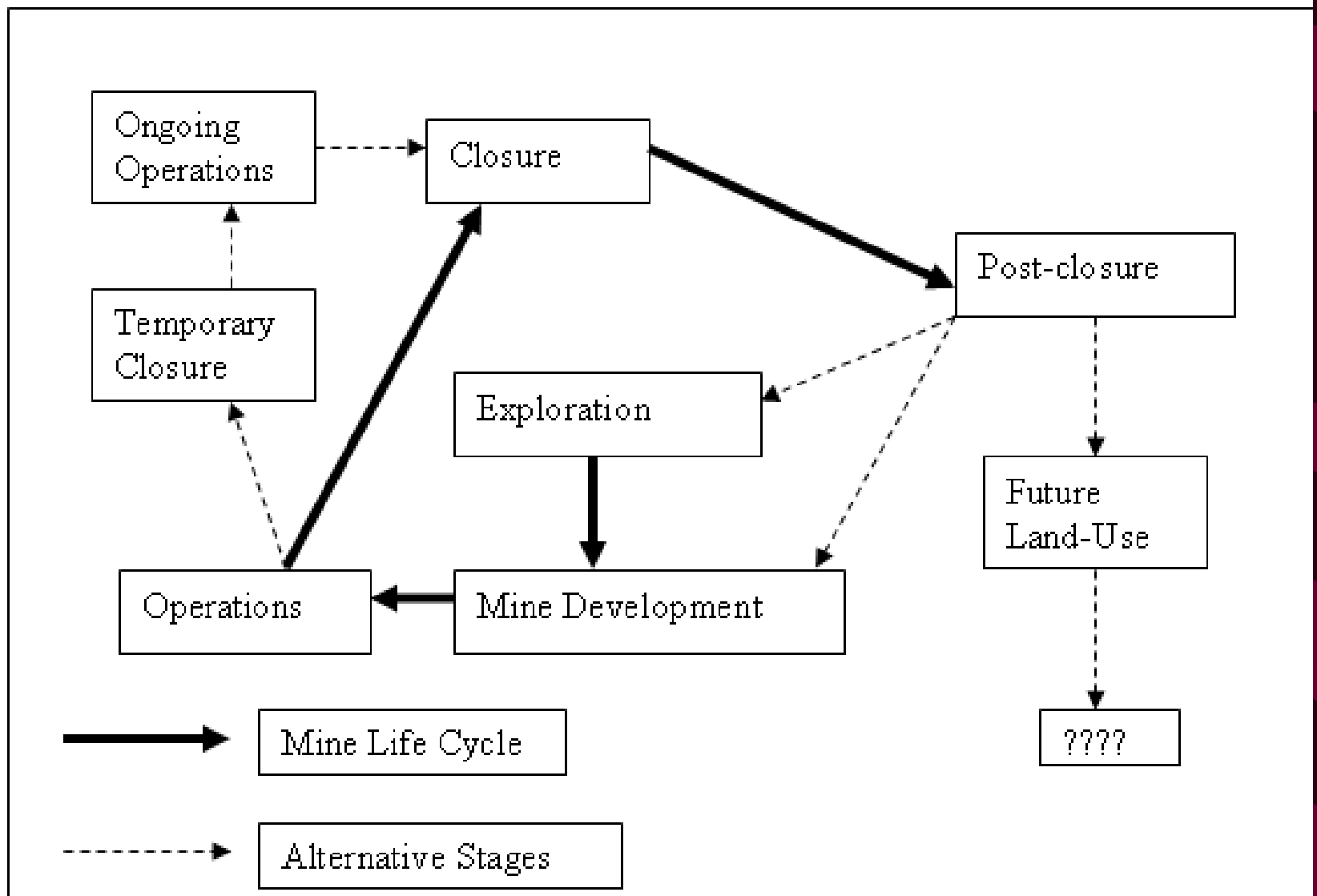
# LIFE CYCLE OF A MINE

The background of the slide features a series of overlapping, wavy, horizontal bands in two shades of blue. The top band is a dark, muted blue, while the lower bands are a lighter, more vibrant blue. These bands create a sense of depth and movement, resembling a stylized landscape or perhaps the layers of a mine. The overall effect is modern and professional.

# Stages of Mining

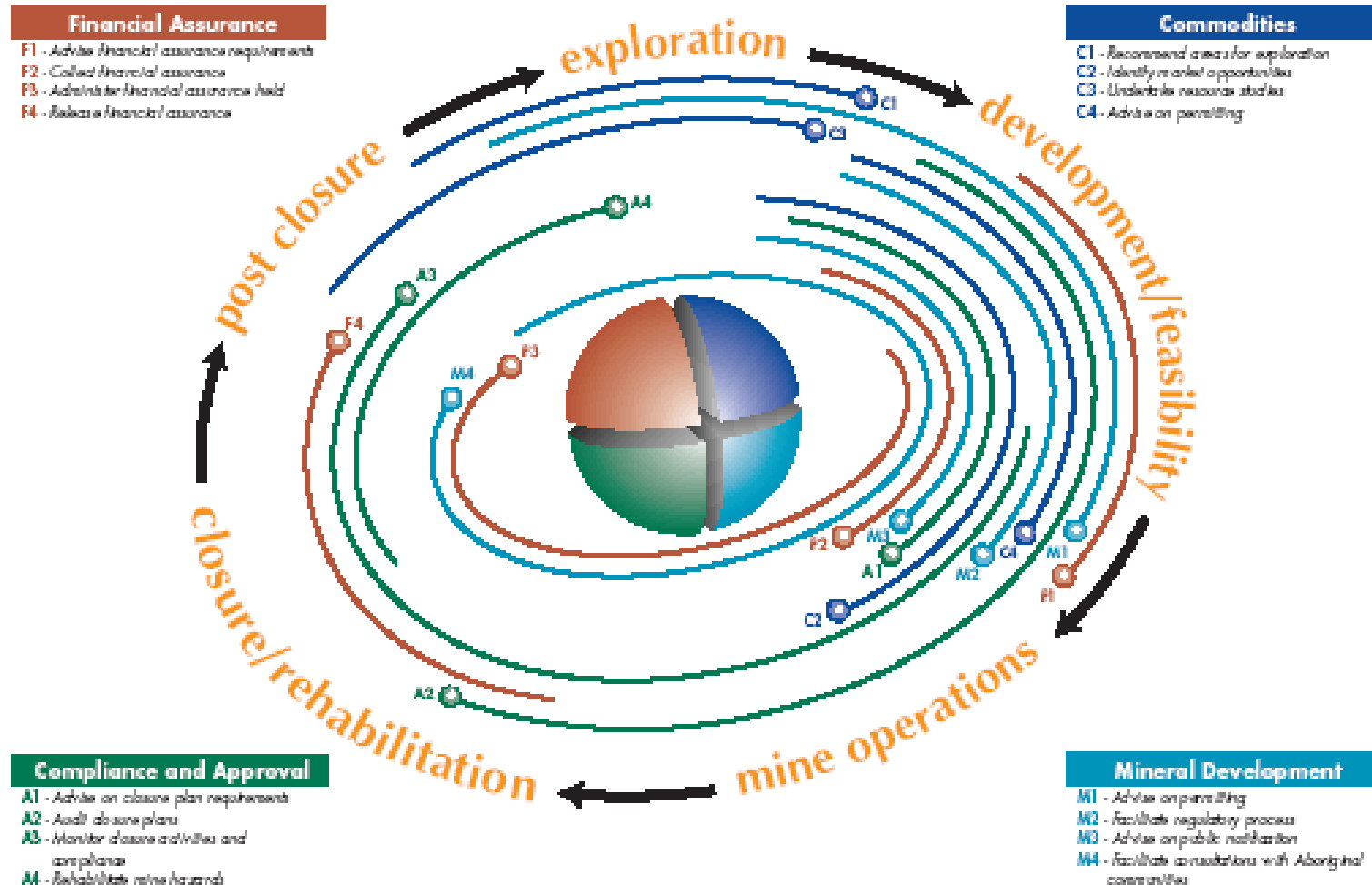
- Exploration (discovery, premining, undisturbed)
  - Mineral resource potential
  - Prefeasibility/Feasibility study
- Mine development (inc. continued exploration)
- Operations (extraction/production/expansion)
  - Processing/beneficiation/milling/smelting/refining
  - Mine expansion/standby
- Marketing
- Closure/postclosure/post-mining use

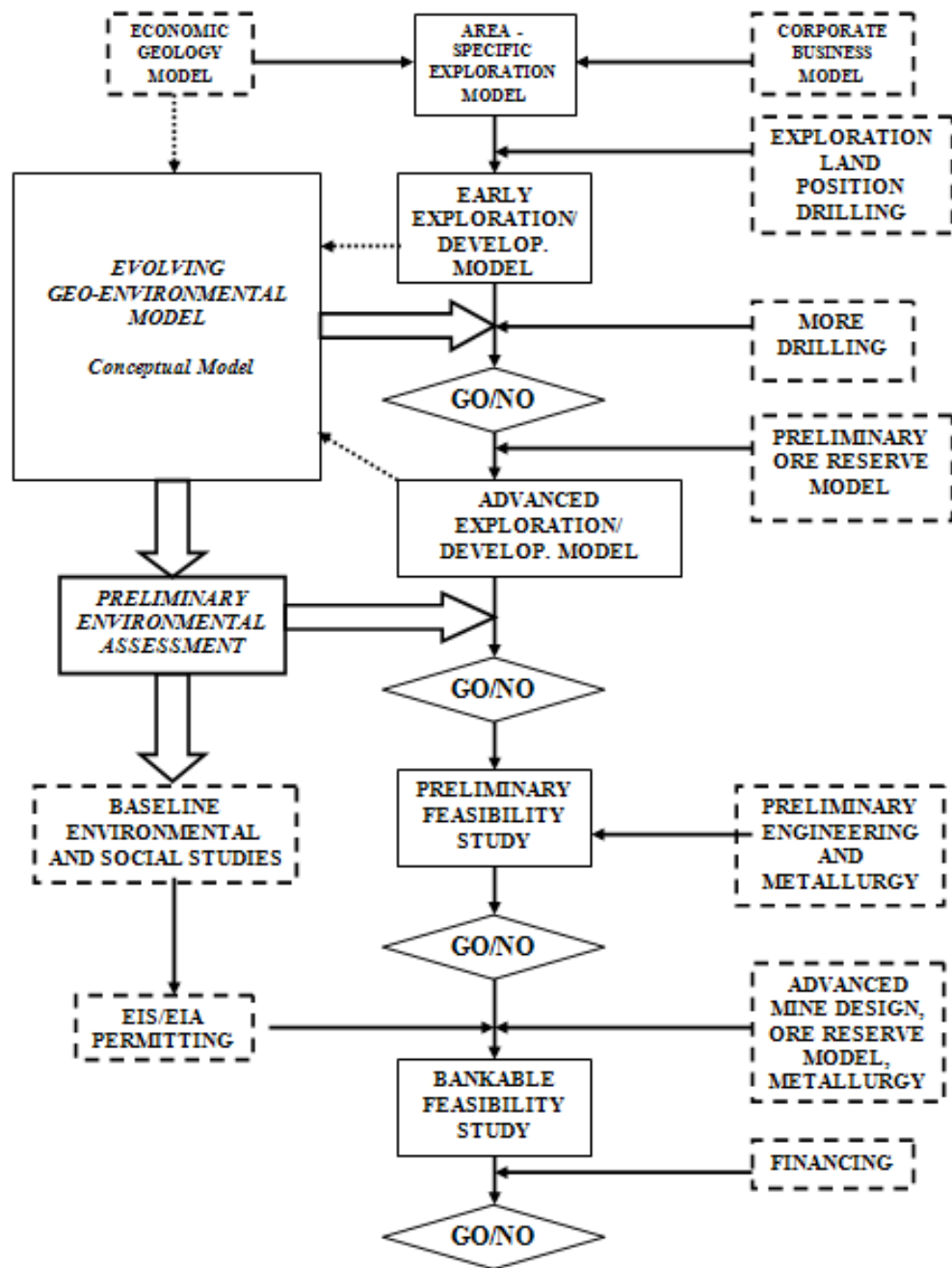




**Figure 13.** Mine Life Cycle Stages (Dirk van Zyl, written communication, March 27, 2002).|

# Mineral Development & Mine Rehabilitation Activities through the Mine Life Cycle





Flowchart summarizing the major steps during project development and integration of geologic, social, economic, and environmental inputs in feasibility studies to determine if a project can proceed to the next stage in the mine life cycle (From McLemore et al., 2014, adapted from Schmiermund and Ranville 2006)

# EXPLORATION



# Exploration

- identification of areas with potential for discovery of an economic mineral deposit
- geology governs the quest
- surveys
- sampling
- geophysics
- drilling
- pits
- shafts, adits
- base-line/pre-existing conditions

# Generation of new project ideas/targets

- Corporate objectives
- Previous experience or knowledge
- Old mining districts
- Recent information
- Literature, including unpublished reports, theses, news releases
- New developments by other companies

# Land Access

- Is the area open to mineral exploration
- Who owns the land
  - federal government
  - state government
  - private
  - Indian
  - other
- Transportation

# SAMPLING AND ANALYSES

- How are you going to sample?
- What are the end-use specifications?
- What processing must occur?



# PREFEASIBILITY STUDY OR PRELIMINARY FEASIBILITY STUDY

- Preliminary feasibility study
- 7.5 months to complete
- Due diligence work
- Is it worth it to continue

# FEASIBILITY STUDY

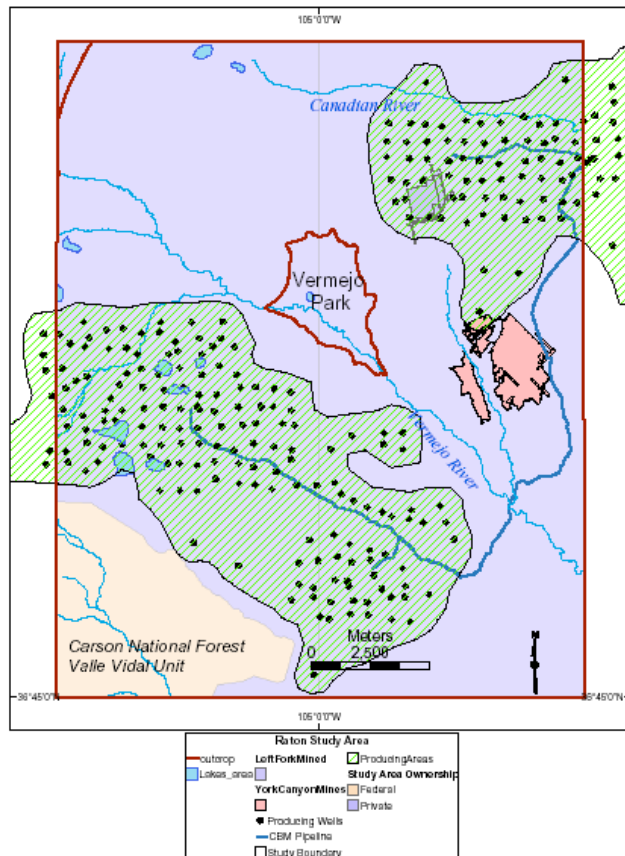


Figure 24. Coalbed methane producing areas as of April 2005 and land ownership in the Raton coalfield study area.

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## NMBGMR Geologic Mapping Program *Open-File Geologic Quadrangle Map Series (OF-GM)*

**Note:** These maps are subject to frequent revisions and may be unavailable when being revised. Map reference dates show the time of initial compilation -- map revision dates, when given, indicate the most current version of the map.

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# FEASIBILITY STUDY

- Intermediate feasibility study 2-3 yrs to complete
- final feasibility study 2-3 yrs to complete
- Is this property economic?
- What are the reserves?
- Can we mine this property?
- Can we market this product?
- What are the environmental consequences?
- What is the land status?

New technologies are being developed that will increase the chance of finding a new deposit, save money, disturb less land, and minimize affects on local communities and cultures.

# Geologic methods

- Robust thermodynamic and kinetic geochemical data and models
- New ore deposit models, especially for deposits with minimal impact on the environment
- More sophisticated 3-dimensional geological and ore reserve models
- Better geohydrologic models relating to mineral deposits, including industrial minerals deposits
- Geologic maps of mineralized areas
- Databases of mineral deposits and mineralized areas

# Geochemical and geophysical methods

- Hand-held and down-hole analytical instruments
- Improved cross-bore hole correlation methods and characterization
- Better understanding of element mobility in soils and water
- Drones (unmanned aircraft) for airborne geophysical methods
- Low-cost, seismic methods
- Better interpretation of remote sensing and hyperspectral data (Livo and Knepper, 2004)
- More sophisticated 3-dimensional geochemical, hydrological, and geophysical models



# UNMANNED AIRBORNE MAGNETICS

(MagSurvey Ltd.,

<http://www.magsurvey.co.uk/>)

# Drilling technologies

- Application of existing petroleum and geothermal techniques to mineral exploration
- Improvements in drilling methods



# Required geologic data

- size, shape, and variability of the ore deposit
- location information
- lithology
- mineralogy--abundance and morphology
- alteration
- structural
- rock competency data

# Report on reserves

- Data Density Integration of Geological Information
- Listing/Recording of Data Set
- Data Analysis
- Sample Support
- Economic Parameters
- Mineral resource Model
- Interpolation Method
- Mineral Resource Validation
- Qualified person
- Geologist/engineer not involved with the company

# Evaluation of potential orebody

- Ore grade: lots of different units, cut-off grade, homogeneity
- By-products: commonly critical to success; Au, Ag, W
- Commodity prices: forecasting the future
- Mineralogical form: native vs sulfide vs oxide vs silicate

# Evaluation of potential orebody

- Grain size and shape: McArthur River 200 Mt, 10% Zn, 4% Pb, 0.2% Cu, 45ppm Ag
- Undesirable substances: As, Sb; calcite in acid leachable U ores
- Size and shape of deposits: underground vs open pit
- Ore character: hard vs soft (blasting, wall support) cost and safety

# Evaluation of potential orebody

- Cost of capital
- Location: infrastructure and transportation
- Environmental considerations: VERY important
- Taxation: involved subject: depreciation,
- Political factors: nationalization, foreign exchange

# MINE DEVELOPMENT





Mine plan or engineering design

**Table 4.7-2 Example WBS numbering system**

<b>Work Area Numbering Sequence</b>	<b>Areas of Work</b>
XX100	Preparation for reviews and management approval
XX200	Land and water status and mapping
XX300	Geology and predevelopment bulk sampling
XX400	Environmental and socioeconomic work (excluding permitting)
XX500	Geotechnical and siting studies, and planning
XX600	Agency reconnaissance, government and public relations, and permitting
XX700	Mining, including a test mine
XX800	Mineral processing and metallurgy sampling and testing (upstream)
XX900	Smelting/refining(downstream)
X1000	Surface and ancillary infrastructure facilities
X1100	Personnel
X1200	Labor planning and relations
X1300	Market investigation and planning
X1400	Financial analysis (cost estimates are within elements 0100 to 1300)
X1500	Tax studies and analysis
X1600	Planning, budgeting, project accounting, and reporting
X1700	Preparation of next step of project, of design basis report, or project closure or alternative action by company

## SME Mine Engineering Handbook



# MINE DEVELOPMENT

- Operations/construction
- lower costs
- site development
- construction
- establish infrastructure
- develop the mine
  - surface (open pit, strip mining)
  - underground (room and pillar, shrinkage stope)
  - solution/leaching

# PROCESSING/BENEFICIATION/ MILLING



# OPERATIONS

## Processing/beneficiation/milling

- Extraction/mining
- crushing (primary, secondary)
- grinding
- concentration (gravity separation, flotation, leaching, SX-EW)
- smelting
- refining
- optimizes the consumption of energy
- new technologies

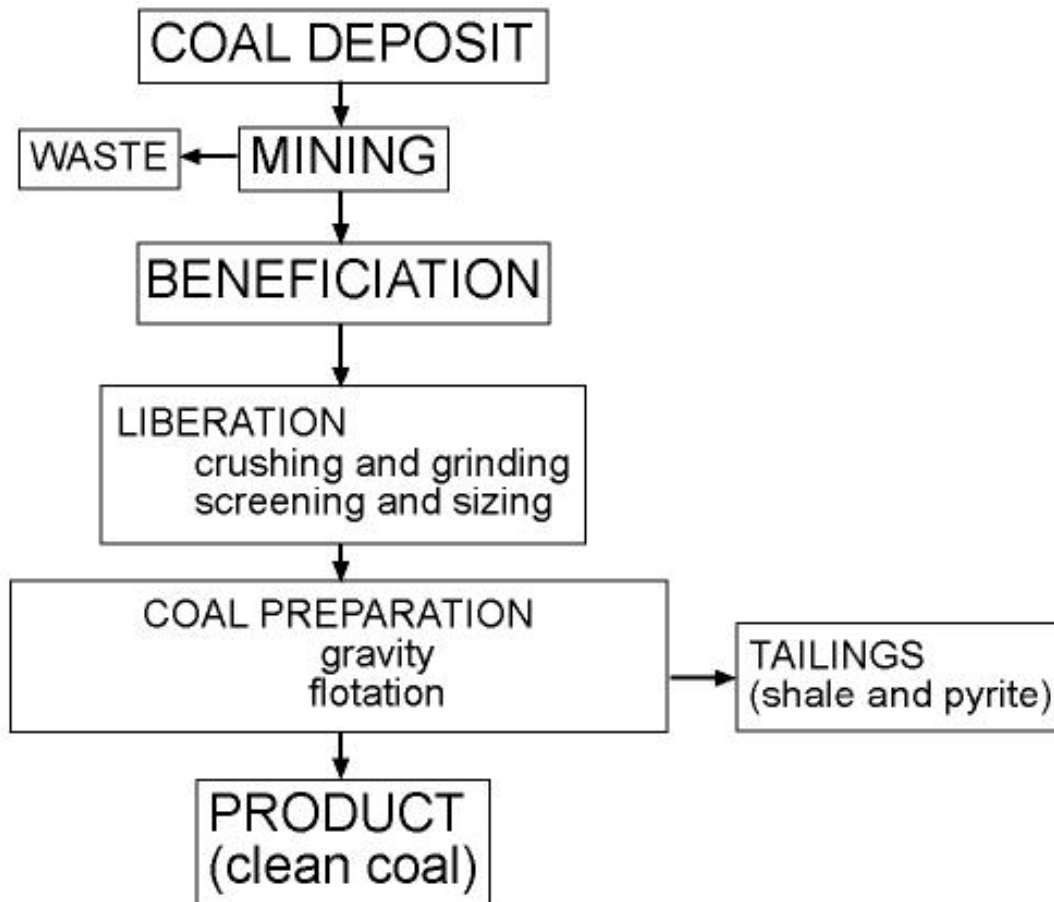


Figure 11. Major steps involved in coal processing.

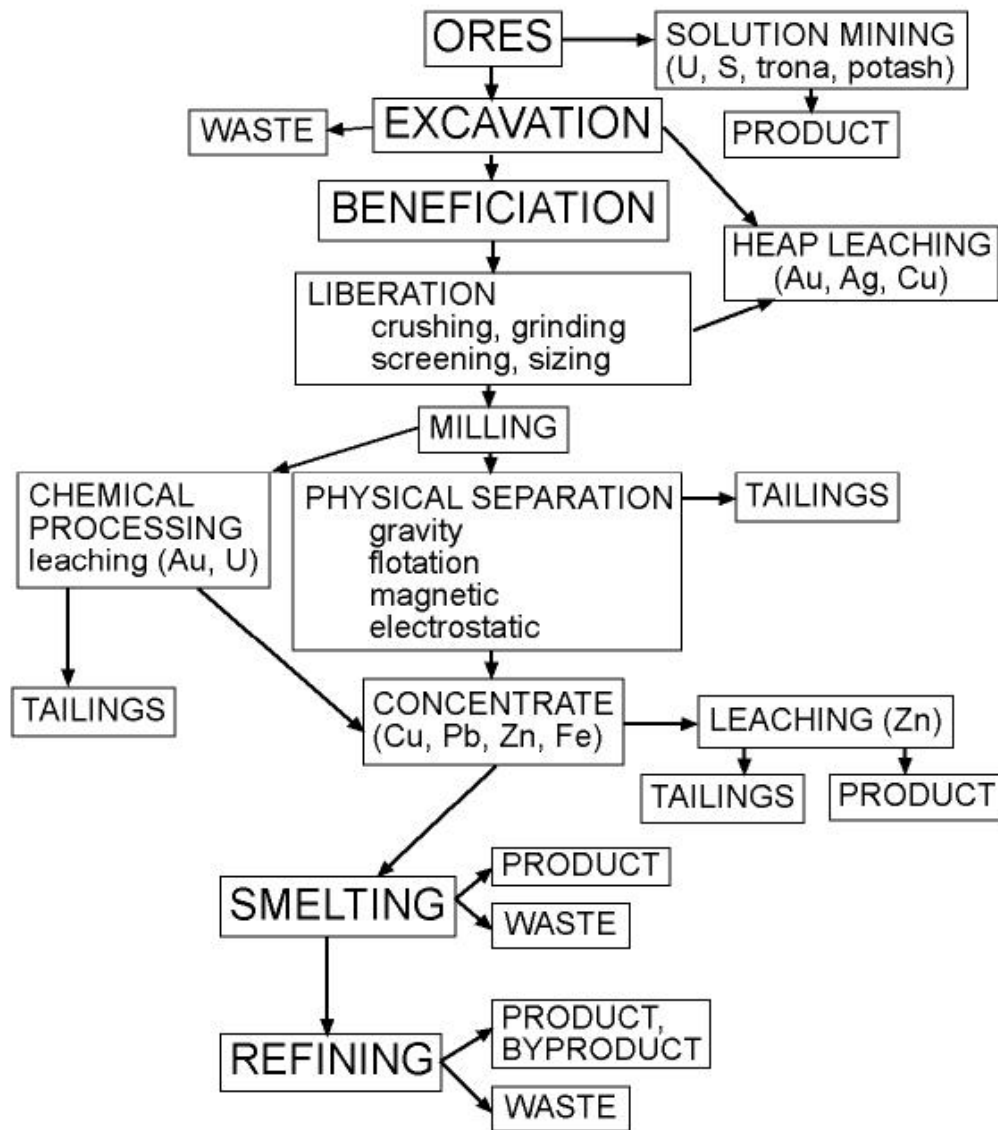


Figure 12. Major steps involved in extraction metallurgy of metals.





CBMM's plant for FeNb crushing and packaging (June 1999) is fully automated. Manual handling was eliminated and replaced by a robot.

[http://www.us.cbmm.com.br/english/sources/mine/operat/f\\_operat.htm](http://www.us.cbmm.com.br/english/sources/mine/operat/f_operat.htm)

# MARKETING





# MARKETING

- Transportation
- Customer specifications
- Clean, recyclable and easily transportable
- Changing markets
  - low cost products
  - have high levels of performance
  - minimal environmental impacts

# CLOSURE/POST-MINING USE



# CLOSURE/POST-MINING USE

- Reclamation
- Sustaining post-mining use
- Close-out plans

# Responsibilities of the geologist

- Exploration--discovery
- Feasibility study--ore body evaluation, reserves
- Mine development--mine design and planning
- Extraction/production--grade control
- Processing/beneficiation/milling
- Marketing--develop a market
- Closure/post-mining use--environmental geology

# JUNIOR COMPANY

- Property that can be sold to investors
- High assays
- Popular commodity
- Current model
- Rarely will mine at this level--expects to sell to a mining company

# MID-SIZE COMPANY

- Must have investor appeal
- Medium to large reserves
- Short term production at a profit--must generate cash flow
- May mine if the deposit is small enough

# LARGE COMPANY

- world class orebody



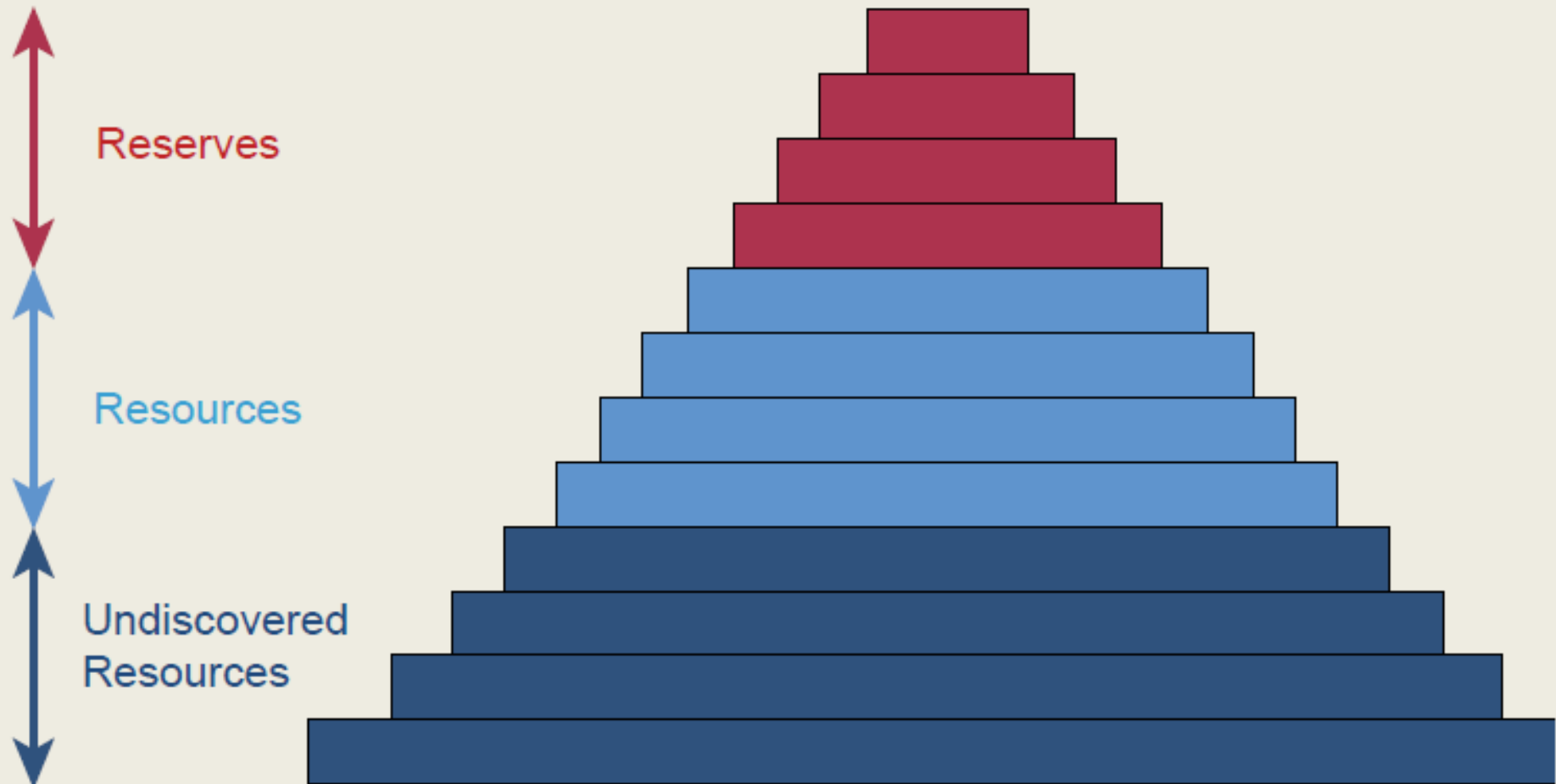
# MANUFACTURING AND CHEMICAL COMPANIES

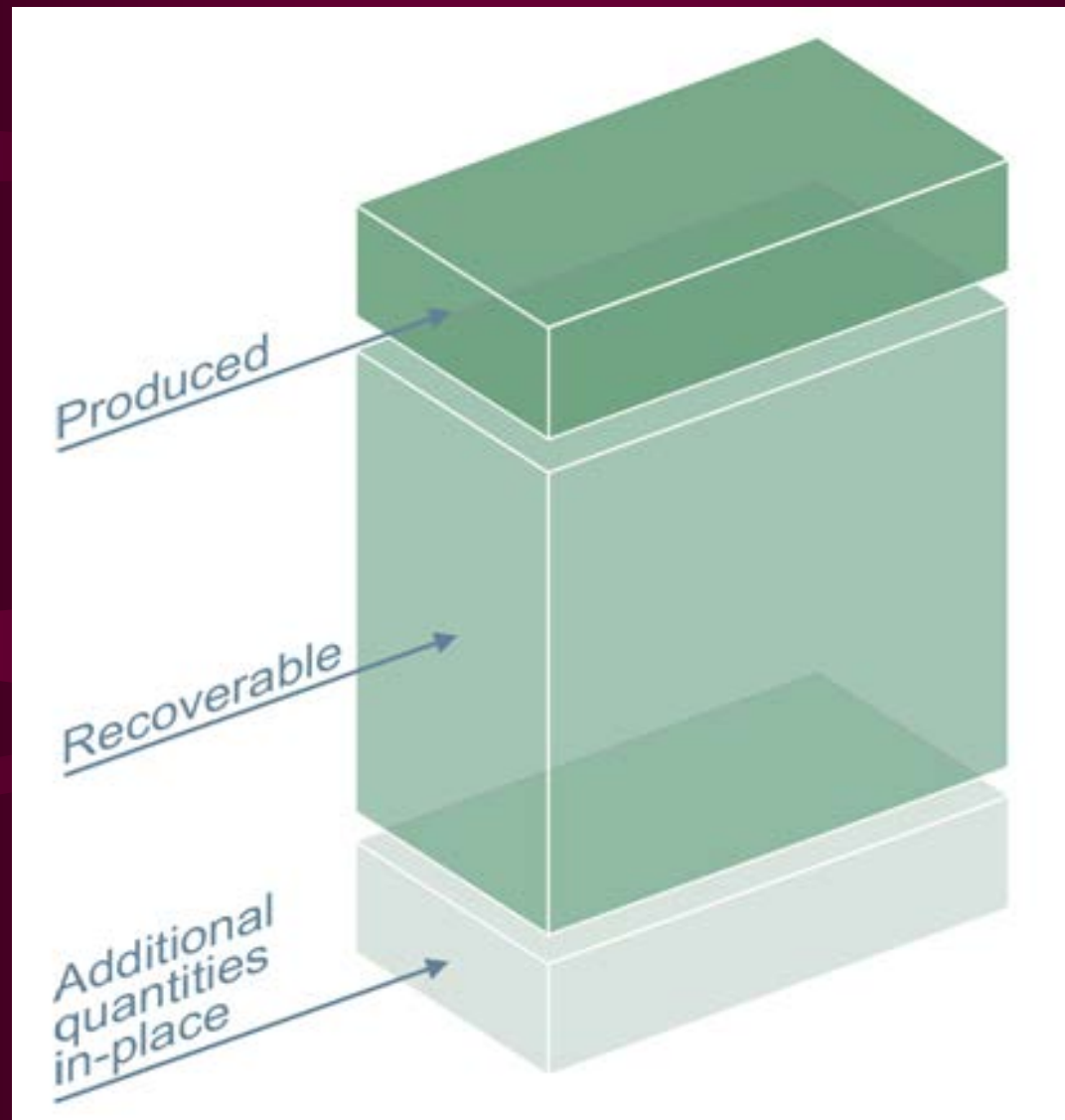
- Specific deposits to meet specific product specifications
- Mines not as important as specifications and long term supply

# **CLASSIFICATION OF RESERVES AND RESOURCES**

# Reserves/Resources (1)

Reserves are currently economic occurrences





# Initial in place resources

([http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=28&ved=0CGsQFjAHOBQ&url=http%3A%2F%2Fwww.world-petroleum.org%2Fdocs%2Fdocs%2FA-UNFC-FINAL.doc&ei=W7TcUMGdHtGNrQHb54DQCw&usg=AFQjCNHqZM3\\_ivXShdaHIZC0sGynGlvTw&sig2=88Yij5U\\_7KyOR-k9QzGZfA&bvm=bv.1355534169,d.aWM](http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=28&ved=0CGsQFjAHOBQ&url=http%3A%2F%2Fwww.world-petroleum.org%2Fdocs%2Fdocs%2FA-UNFC-FINAL.doc&ei=W7TcUMGdHtGNrQHb54DQCw&usg=AFQjCNHqZM3_ivXShdaHIZC0sGynGlvTw&sig2=88Yij5U_7KyOR-k9QzGZfA&bvm=bv.1355534169,d.aWM))

**Table 1. The UNFC in matrix form applied to coal, uranium and other solid minerals**

UN International Framework ↓	National System ↓	Detailed Exploration	General Exploration	Prospecting	Reconnaissance
Feasibility Study and/or Mining Report		1 (111)	usually		
		2 (211)			
Prefeasibility Study		1 (121) + (122)	not relevant		
		2 (221) + (222)			
Geological Study*)		3 (331)	3 (332)	3 (333)	3 (334)

Economic Viability  
Categories:

1: economic  
2: potentially economic

3: intrinsically economic (economic to potentially economic)

# RESERVES

- *Inferred*: That part of a Mineral Resource for which tonnage, grade and mineral content can be estimated with a low level of confidence.
- *Indicated*: That part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a reasonable level of confidence.
- *Measured*: That part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a high level of confidence.

## Geologically Defined

Broadly Delineated

Moderately Delineated

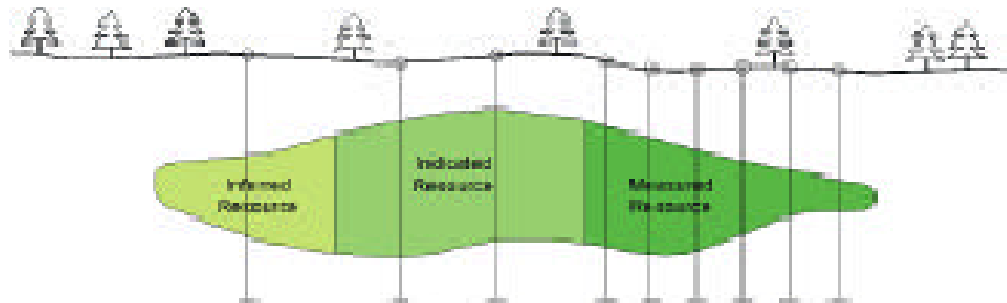
Highly Delineated

Increasing Geologic  
Confidence  
↓

Inferred

Indicated

Measured

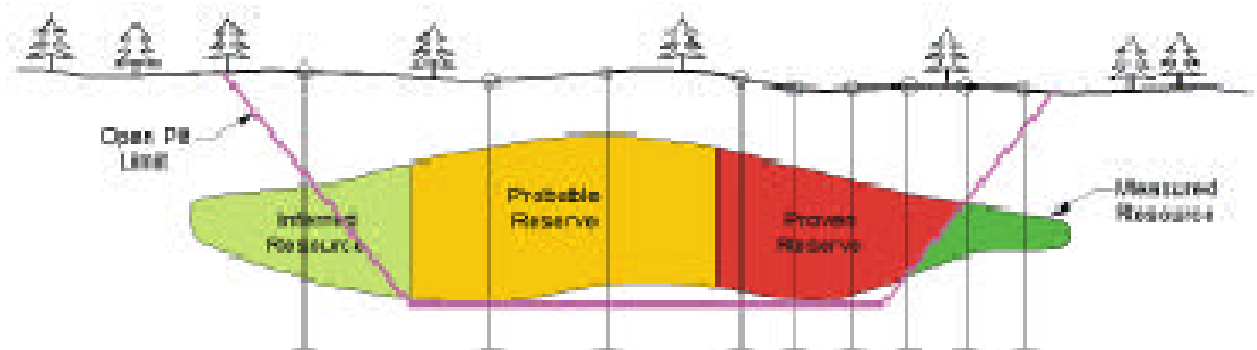




# RESERVES

- *Probable*: The economically mineable part of an Indicated and, in some circumstances, Measured Mineral Resource.
- *Proven*: The economically mineable part of a Measured Mineral Resource.

## Economic Viability Defined



## DEFINITIONS OF LEVEL OF RESOURCE POTENTIAL

- N**     **No mineral resource potential** is a category reserved for a specific type of resource in a well defined area.
- L**     **Low mineral-resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics indicated geologic environment where the existence of mineral resources is unlikely and is assigned to areas of no or dispersed mineralized rocks.
- M**     **Moderate mineral-resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence.
- H**     **High mineral-resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence. Assignment of high mineral-resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

## DEFINITIONS OF LEVEL OF CERTAINTY

- A**     Available information is not adequate for the determination of the level of mineral resource potential.
- B**     Available information suggests the level of mineral-resource potential.
- C**     Available information gives a good indication of the level of mineral-resource potential.
- D**     Available information clearly defines the level of mineral-resource potential.

INCREASING LEVEL OF RESOURCE POTENTIAL	U/A Unknown Potential	H/B High Potential	H/C High Potential	H/D High Potential
		M/B Moderate Potential	M/C Moderate Potential	M/D Moderate Potential
		L/B Low Potential	L/C Low Potential	L/D Low Potential
				N/D No Potential
INCREASING LEVEL OF CERTAINTY				

**FIGURE 48.** Classification of mineral-resource potential and certainty of assurance (modified from Goudarzi, 1984).

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		L/B Low Potential	L/C Low Potential	L/D Low Potential
				N/D No Potential
INCREASING LEVEL OF CERTAINTY				

“A mineral is where you find it.  
It may not be the most suitable  
place in the world.”

U.S. Senator Larry Craig, explaining  
why he is seeking to lift limits on  
mine waste dumping on  
public lands

Many strategic and critical mineral deposits differ significantly from other, more typical metallic mineral deposits and even amongst themselves.



Customer specifications for many strategic and critical minerals products are frequently based solely on physical properties rather than, or in addition to, chemical characteristics.

Determination of the chemical and physical characteristics of a strategic and critical mineral often involves procedures and tests that are not part of the normal activity of an analytical laboratory.

Published specifications and standards for strategic and critical minerals should be used primarily as a screening mechanism to establish the marketability of the mineral. The suitability of an strategic and critical mineral for use in specific applications can only be determined through detailed market investigations and discussions with potential consumers.

BreX

# Bre-X Scandal: A History Timeline

- 1989 David Walsh flunded Bre-X Minerals as a subsidiary of Breaea Resources Ltd.
- 1993 Walsh bought a property near Busang River, Borneo, Indonesia
- 1994 drilled

# Bre-X Scandal: A History

## Timeline-2

- But project manager Michael de Guzman was filing gold from his wedding ring and adding the flakes to the crushed core samples
- De Guzman used realistic ratios of gold to rock and the project kept going
- De Guzman then bought \$61k of panned gold from the locals to use in salting

# Bre-X Scandal: A History

## Timeline-3

- Independent auditors were fooled
- Reported 200 million oz of gold (\$240 billion in 2014 prices)
- De Guzman, Felderhoff, and Walsh sold some of their options for \$100 million
- 1996 Indonesia revoked their exploration permits
- 1997 a fire destroys many of the sample records



# Bre-X Scandal: A History

## Timeline-4

- 1997 Joint venture established between Indonesia (40%), Bre-x (45%), and Freeport McMoRan (15%)
- Freeport begins due diligence and twin previously drilled holes
- Freeport reports minor amounts of gold
- De Guzman falls to his death from a helicopter on the way to meet Freeport geologists

# **GEOLOGY OF STRATEGIC AND CRITICAL MINERALS DEPOSITS**

Geology provides the framework  
in which mineral exploration  
and the integrated procedures of  
remote sensing, geophysics,  
and geochemistry are planned  
and interpreted.

# Factors important in evaluating a strategic and critical minerals deposit

- Customer specifications
- Distance to customer (transportation)
- Ore grade--concentration of the commodity in the deposit
- By-products
- Commodity prices
- Mineralogical form
- Grain size and shape
- Origin of ore-bearing fluids

# Factors--continued

- Undesirable substances
- Size, attitude and shape of deposit
- Process of deposition (replacement, open-space filling)
- Ore character
- Cost of capital
- Location
- Environmental consequences/  
reclamation/bonding
- Land status
- Taxation

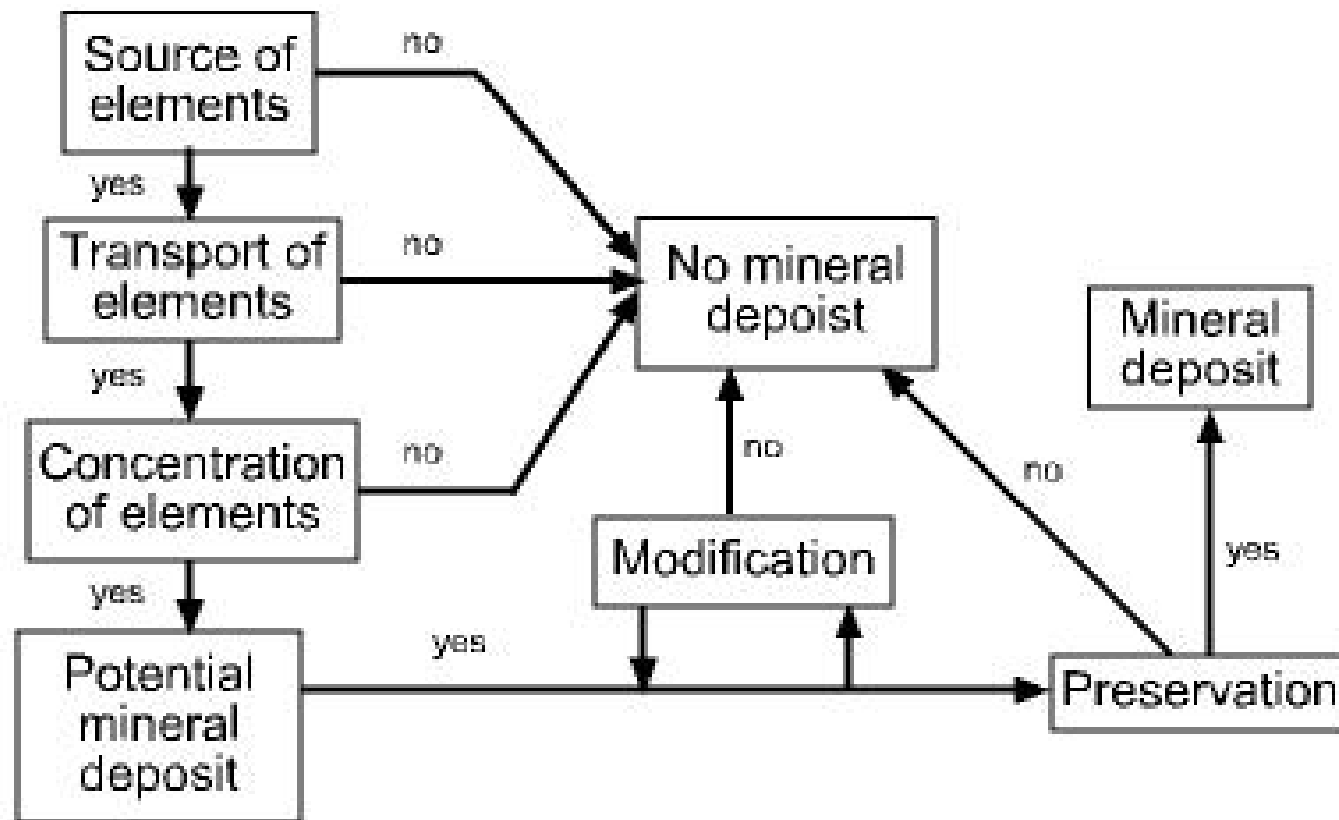


Figure 1. Conceptual model for the formation of a mineral deposit (after Tilsley, 1990).

# **TYPES OF MINERAL DEPOSITS**



# Classifications

- Niggli (1929) (historic, considered deposits related to magmatic process)
- Schneiderhohn (1941) (historic, considered deposits related to magmatic process)
- Lindgren (1933, modified 1968) (all types)
- Bateman (1942, revised 1979) (all types)
- Stanton (1972)
- Guilbert and Park (1986)
- Cox and Singer (1986)

## **I. Plutonic, or intrusive**

### **A. Orthomagmatic**

1. Diamond, platinum-chromium
2. Titanium-iron-nickel-copper
  - a. Iron-nickel-copper sulfide/arsenide
  - b. Titanium-iron oxide

### **B. Pneumatolytic to pegmatitic**

1. Heavy metals - alkaline earths - phosphorus - titanium
  - a. Copper-lead-zinc
  - b. Tourmaline-rutile
2. Silicon-alkali metals-fluorine-boron-tin-molybdenum-tungsten
3. Tourmaline-quartz

### **C. Hydrothermal**

1. Iron-copper-gold-arsenic
2. Lead-zinc-silver
3. Nickel-cobalt-arsenic-silver
4. Carbonates-oxides-sulfates-fluorides

## **II. Volcanic, or extrusive**

- A. Tin-silver-bismuth
- B. Heavy metals
- C. Gold-silver
- D. Antimony-mercury
- E. Native copper
- F. Subaquatic-volcanic and biochemical deposits

Niggli (1929)

- I. Intrusive and liquid-magmatic deposits
- II. Pneumatolytic deposits
  - A. Pegmatitic veins
  - B. Pneumatolytic veins and impregnations
  - C. Contact pneumatolytic replacements
- III. Hydrothermal deposits
  - A. Gold and silver associations
  - B. Pyrite and copper associations
  - C. Lead-silver-zinc associations
  - D. Silver-cobalt-nickel-bismuth-uranium associations
  - E. Tin-silver-tungsten-bismuth associations
  - F. Antimony-mercury-arsenic-selenium associations
  - G. Nonsulfide associations (Iron-manganese-magnesium oxide/carbonate)
  - H. Nonmetallic associations (Fluorite-barite-quartz)
- IV. Exhalation deposits

**Schneiderhohn (1941)**

I. Deposits produced by chemical processes of concentration, transportation and pressure vary between wide limits.

A. In oceans, by processes of differentiation.

1. *Algebraic deposits proper, magmatic segregation deposits, injection deposits.*

Temperature: 700°-1500°C; pressure very high.

2. *Pegmatites.* Temperature very high to moderate; pressure very high.

II. In bodies of rocks.

1. *Concentration affected by introduction of substances foreign to the rock (epigenetic).*

a. *Origin dependent upon the nature of igneous rocks.*

i. *Volcanogenic,* deposits associated usually with volcanic glass.

Temperature: 100°- 600°C; pressure moderate to atmospheric.

ii. *From effusive bodies.* Sublimates, fumes etc. Temperature: 100°- 600°C; pressure moderate to atmospheric.

iii. *From intrusive bodies.* Igneous metamorphic deposits. Temperature probably 600°- 800°C; pressure very high.

b. *By hot ascending masses of uncertain origin, possibly magmatic, metamorphic, oceanic, cosmic, or cosmic.* Hydrothermal deposits.

i. *Hypothermal deposits.* Deposition and concentration at great depths or at high temperature and pressure. Temperature: 300°- 500°C; pressure very high.

ii. *Mesothermal deposits.* Deposition and concentration at intermediate depths. Temperature: 200°-300°C; pressure high.

iii. *Epithermal deposits.* Deposition and concentration at slight depths. Temperature 50°-200°C; pressure moderate.

iv. *Telothermal deposits.* Deposition from nearly spent solutions. Temperature and pressure low; upper members of the hydrothermal range.

v. *Xenothermal deposits.* Deposition and concentration at shallow depths, but at high temperatures. Temperature high to low; pressure moderate to atmospheric.

c. *Origin by circulating metamorphic masses at moderate or slight depths.* Temperature up to 100°C; pressure moderate.

2. *By concentration of substances contained in the igneous body itself.*

a. *Concentration by dynamic and regional metamorphism.* Temperature up to 400°C; pressure high.

b. *Concentration by groundwater of deeper circulation.* Supergene enrichment. Temperature up to 100°C; pressure moderate.

c. *Concentration by rock decay and residual weathering near surface.* Temperature up to 100°C; pressure atmospheric to moderate.

C. In bodies of water.

1. *Hydrothermal.* Underwater springs associated with volcanism. Temperature high to moderate; pressure low to moderate.

2. *By interaction of solutions.* Sedimentary deposits. Temperature up to 70°C; pressure moderate.

a. *Inorganic reactions.*

b. *Organic reactions.*

3. *By evaporation of solutions.*

II. Deposits produced by mechanical processes of concentration. Temperature and pressure moderate to low.

Lindgren,  
1933)

1. Magmatic concentration. High T and P.
  - I. Early magmatic.
    - A. Disseminated crystallization.
    - B. Segregation.
    - C. Injection.
  - II. Late magmatic.
    - A. Residual liquid segregation.
    - B. Residual liquid injection.
    - C. Immiscible liquid segregation.
    - D. Immiscible liquid injection.
2. Sublimates. Low T and P.
3. Contact metamorphism. Intermediate to high T and P.
4. Hydrothermal processes. T and P conditions from low to high.
  - I. Telothermal
  - II. Epithermal
  - III. Leptothermal
  - IV. Mesothermal
  - V. Hypothermal
  - VI. Xenothermal
5. Sedimentation. Low T and P.
6. Bacteriogenic.
7. Submarine exhalative volcanism. Low to high T and P.
8. Evaporation. Low T and P.
  - I. Marine
  - II. Lake
  - III. Groundwater
9. Residual and Mechanical Concentration. Low T and P.
  - I. Residual concentration.
  - II. Mechanical concentration. Placers.
    - A. Stream
    - B. Beach
    - C. Eluvial
    - D. Eolian
10. Surficial oxidation and supergene enrichment. Low T and P.
11. Metamorphism. Intermediate to high T and P.
  - I. Metamorphosed deposits.
  - II. Metamorphic deposits.

# Bateman

## (1942, revised 1979)

## I. Igneous associations

### A. Mafic and ultramafic associations

1. Cr-Ni-Platinum Group Elements
2. Fe-Ni-Cu-S-Platinum Group Elements

### B. Felsic associations

1. Carbonatite-Rare Earths-Cu-P
2. Anorthosite-Fe-Ti
3. Quartz monzonite-granodiorite-Cu-Mo-S

## II. Sedimentary affiliations

- A. Fe, B. Mn, C. Limestone-Pb-Zn, D. Sandstone-U-V-Cu, E. Conglomerate-Au-U.  
Pyrite

## III. Marine-Volcanic associations

## IV. Vein associations

- A. Precious metal-Te, B. Base metal-S, C. Ag-Co-Ni-As

## V. Metamorphic Affiliations

- A. Contact metamorphism  
B. Regional metamorphism  
C. Dislocation metamorphism

Stanton (1972)

- I. Mafic igneous rock associations
  - A. Layered mafic intrusions
  - B. Anorthosites
  - C. Kimberlites
  - D. Carbonatites
  - E. Ultramafic volcanic rocks
- II. Oceanic crust associations
- III. Intermediate to felsic intrusion associations
  - A. Igneous iron deposits
  - B. Porphyry base-metal deposits
  - C. Hydrothermal iron deposits
  - D. Cordilleran vein-type deposits
  - E. Pegmatites
  - F. Granitic tin and uranium deposits
- IV. Subaerial volcanic associations
- V. Submarine volcanic associations
  - A. Volcanogenic massive sulfides
  - B. Banded iron formations
  - C. Echalite gold deposits
- VI. Submarine volcanic-sedimentary associations
- VII. Chemical sedimentation
  - A. Sedimentary base-metal deposits
  - B. Sedimentary iron deposits
  - C. Sedimentary manganese deposits
  - D. Phosphate deposits
  - E. Evaporites
  - F. Manganese nodules
- VIII. Clastic sedimentation (Placers)
- IX. Weathering
  - A. Laterites
  - B. Supergene sulfide enrichment
- X. Regional metamorphism
- XI. Solution-remobilization
- XII. Epigenetic deposits of doubtful igneous connection
  - A. Mississippi Valley type Pb-Zn
  - B. Colorado Plateau type U
- C. Unconformity-related U

# Guilbert and Park (1986)



GEOLOGIC ENVIRONMENT		Deposit Models
Igneous	Intrusive	<div> <div> Mafic-ultramafic </div> <div> Stable Area — 1 to 4 Unstable Area — 5 to 10 </div> </div>
		Alkaline and basic — 11 to 12
		<div> Felsic </div> <div> Phanerocrystalline — 13 to 15 Porphyroaphanitic — 16 to 22 </div>
	Extrusive	Mafic — 23 to 24
		Felsic - mafic — 25 to 28
	Sedimentary	<div> Clastic rocks — 29 to 31 Carbonate rocks — 32 Chemical sediments — 32 to 35 </div>
Regional Metamorphic		Metavolcanic and metasedimentary — 36
		Metapelite and metaarenite — 37
Surficial		Residual — 38
		Depositional — 39

Cox and Singer (1985)

# **Epigenetic mineral deposit**

**formed much later than the rocks which  
enclose it**

# **Syngenetic mineral deposit**

**formed at the same time as the rocks that  
enclose it**

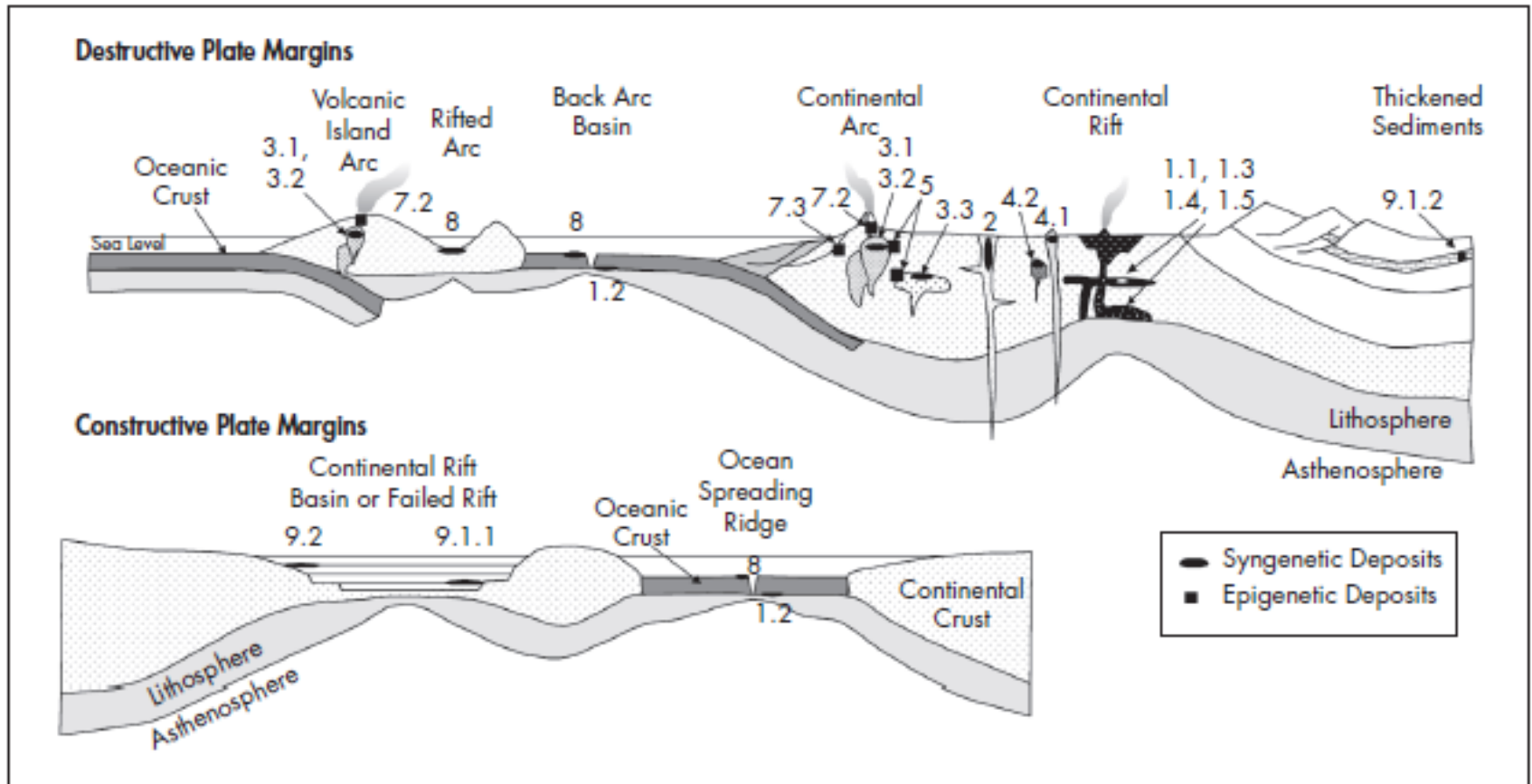


Figure 3.1-1 Plate tectonic settings for key magmatic and hydrothermal deposit types (numbers refer to deposit classes and types shown in Table 3.1-1)

# Why do we classify mineral deposits?



# Why do we classify mineral deposits?

- geological conditions of formation
- how they formed
- where they formed
- exploration

# Simple classification

- magmatic
- sedimentary
- supergene
- metamorphic

# Deposit Groups

<http://www.empr.gov.bc.ca/Mining/Geoscience/MineralDepositProfiles/ListbyDepositGroup/Pages/default.aspx>

- Organic
- Residual/surficial
- Palcer
- Continental sediments and volcanics
- Sediment-hosted
- Chemical sediment
- Marine volcanic association
- Epithermal
- Vein, breccia and stockwork
- Manto
- Skarn
- porphyry
- Ultramafic/mafic
- Carbonatites
- Pegmatites
- Metamorphic-hosted
- Gems, semi-precious stones
- Industrial rocks
- other



# Lithology

- Unconsolidated deposits
- Sedimentary rocks
- Volcanic rocks
- Intrusive rocks
- Regionally metamorphosed rocks

<http://www.empr.gov.bc.ca/Mining/Geoscience/MineralDepositProfiles/LithologicalListing/Pages/default.aspx>

# Commodity

- <http://www.empr.gov.bc.ca/Mining/Geoscience/MineralDepositProfiles/Pages/ListingbyCommodity.aspx>

Some deposits are formed by more than one process (placers, some nepheline syenites)

# Mineral deposit models - what are they?

- Systematically arranged information describing the essential attributes of a class of mineral deposits
- Two end-member types:
  - descriptive or empirical
  - genetic or conceptual
- Many commodities and many deposit types
- **Deposit type** - name, commodities, examples
- **Economic characteristics** - importance, grade and tonnage
- **Geological features** - setting, host rocks, morphology, mineralogy, alteration, paragenesis, age of host rocks, age of ore, geochemical and geophysical features
- **Genetic aspects** - sources of metals, fluids, etc; controls on sites of mineralisation.
- **Exploration methodology**

# Mineral deposit models - why are they useful?

- Allow comparison between deposits and classification of new discoveries
- Establish a deposit signature or fingerprint, allowing **prediction** of the location of new targets
- Assist in defining exploration methodology and strategy
- They are dynamic: can be continually refined as more data becomes available

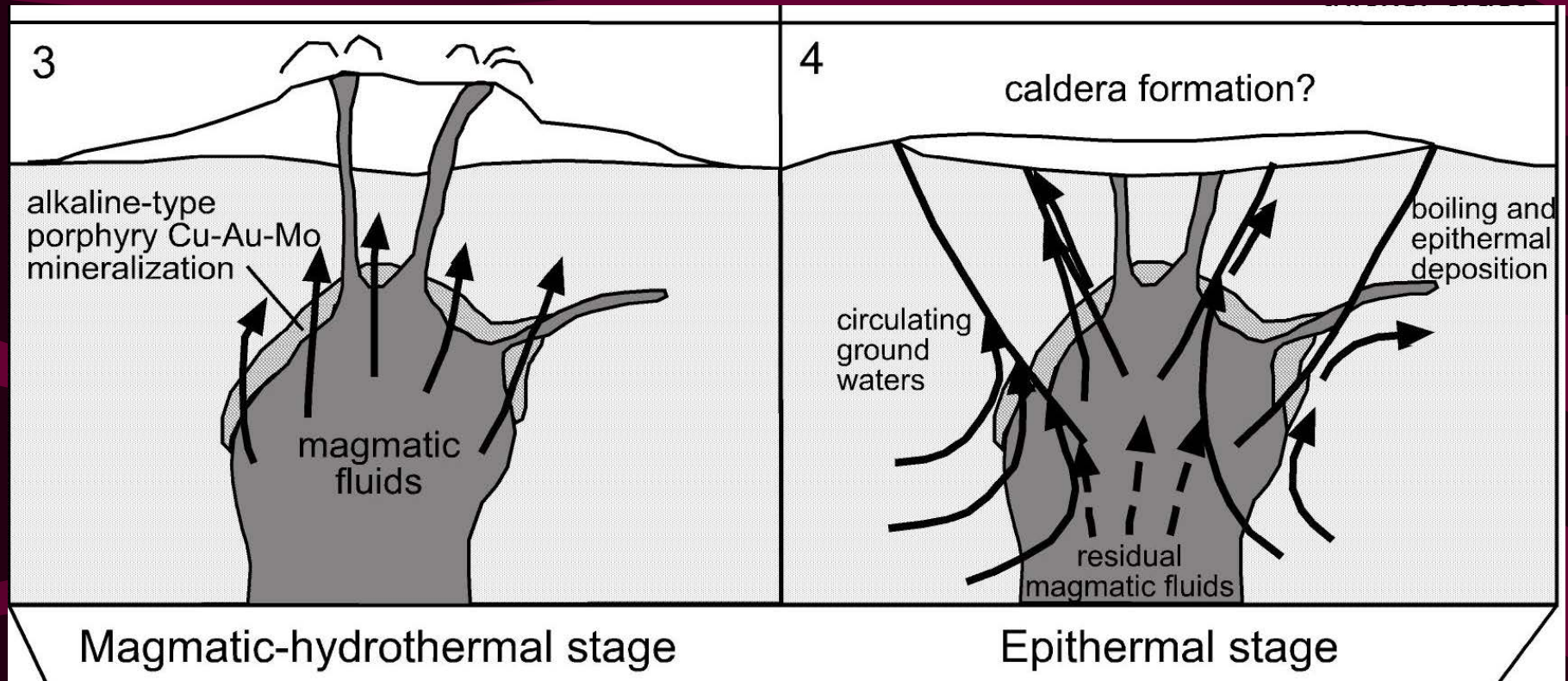
# Genetic processes that lead to the concentration of minerals

- Hydrothermal mineral deposits formed in association with magma and water
- Magmatic mineral deposits concentrated in igneous rocks (crystallization verses segregation)
- Sedimentary mineral deposits precipitated from a solution, typically sea water
- Placer deposits sorted and distributed by flow of water (or ice) and concentrated by gravity
- Residual mineral deposits formed by weathering reactions at the earth's surface

# Genetic processes--continued

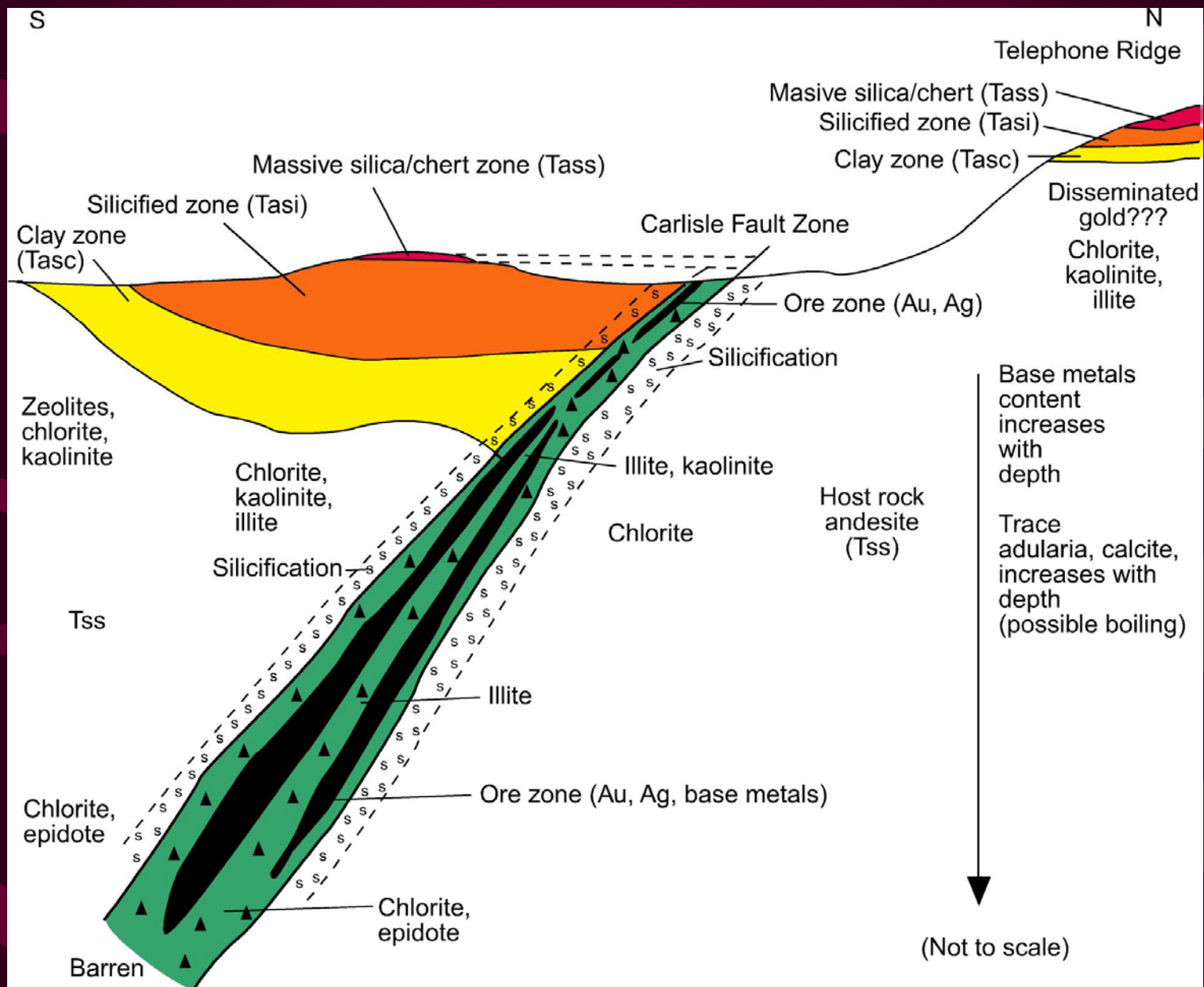
- Lateral secretion or diffusion of minerals from country rocks into faults and other structures
- Metamorphic processes, both contact and regional
- Secondary or supergene enrichment where leaching of materials occurs and precipitation at depth produces higher concentrations
- Volcanic exhalative





Hydrothermal mineral deposits formed in association with magma and water





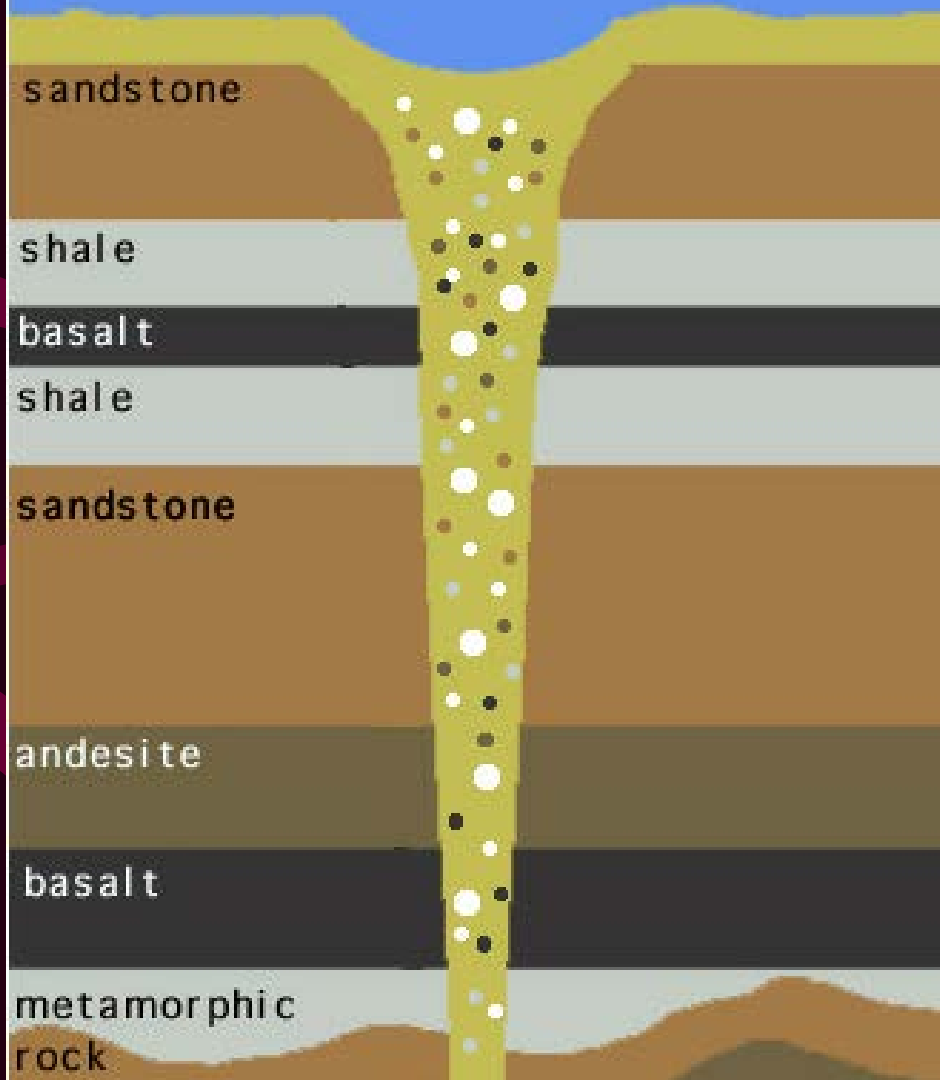
Relationship between alteration and vein deposits along the Carlisle fault (modified in part from Weaco drill data).



Magmatic mineral deposits concentrated  
in igneous rocks (crystallization verses  
segregation)

[http://jove.geol.niu.edu/faculty/fischer/105\\_info/105\\_E\\_notes/lecture\\_notes/Mineral\\_Resources/MR\\_images/pegmatite.jpeg](http://jove.geol.niu.edu/faculty/fischer/105_info/105_E_notes/lecture_notes/Mineral_Resources/MR_images/pegmatite.jpeg)

## Diamonds in Kimberlite Pipes



[http://jove.geol.niu.edu/fischer/105\\_info/105\\_E\\_notes/lecture\\_notes/Mineral\\_Resources/MR\\_images/kimberlite\\_pipe.jpeg](http://jove.geol.niu.edu/fischer/105_info/105_E_notes/lecture_notes/Mineral_Resources/MR_images/kimberlite_pipe.jpeg)



**Figure 22.** Photograph showing a 60 cm thick seam of black chromite ore layered within the ultramafic rocks at Red Mountain.

<http://pubs.usgs.gov/bul/b2156/b2156.pdf>



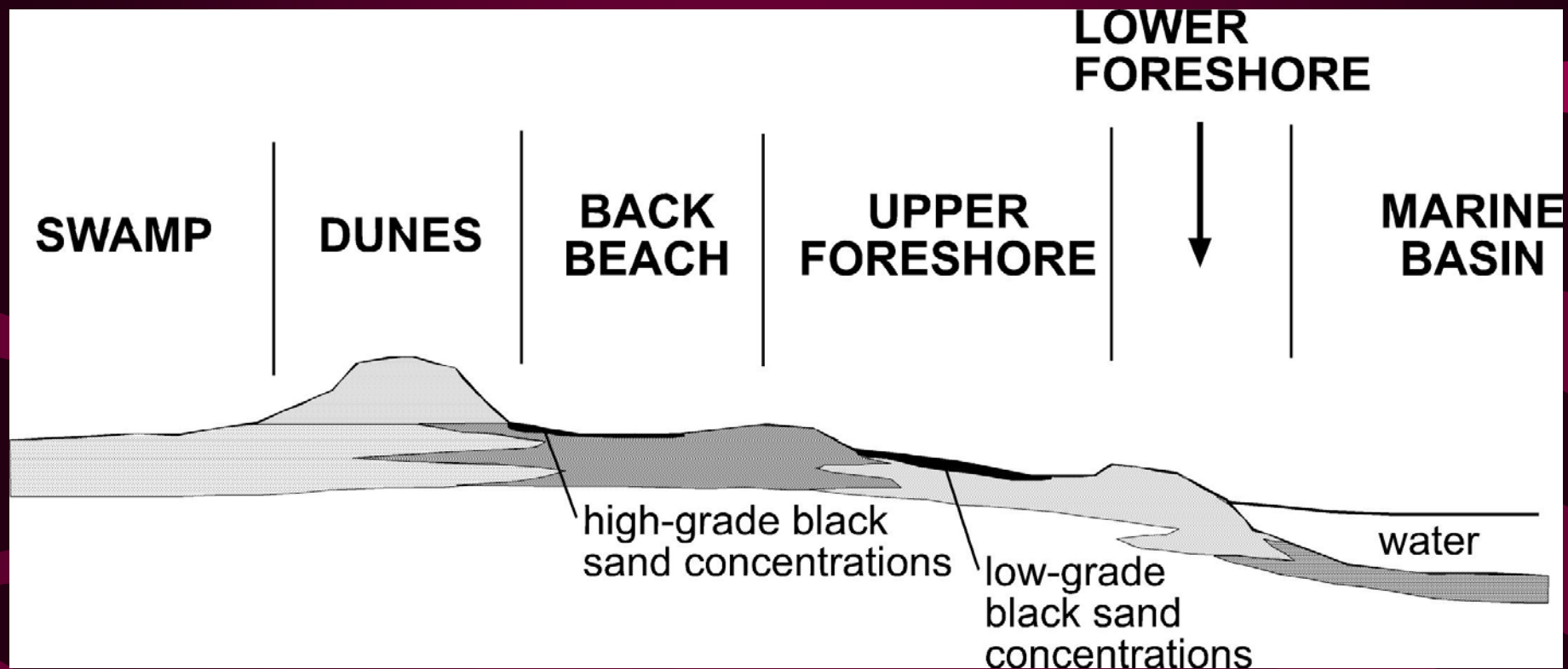
**Sedimentary mineral deposits precipitated  
from a solution, typically sea water**

[http://jove.geol.niu.edu/faculty/fischer/105\\_info/105\\_E\\_notes/lecture\\_notes/Mineral\\_Resources/MR\\_images/death\\_valley\\_salt\\_flats.jpg](http://jove.geol.niu.edu/faculty/fischer/105_info/105_E_notes/lecture_notes/Mineral_Resources/MR_images/death_valley_salt_flats.jpg)





Placer deposits sorted and distributed by flow of water (or ice) and concentrated by gravity

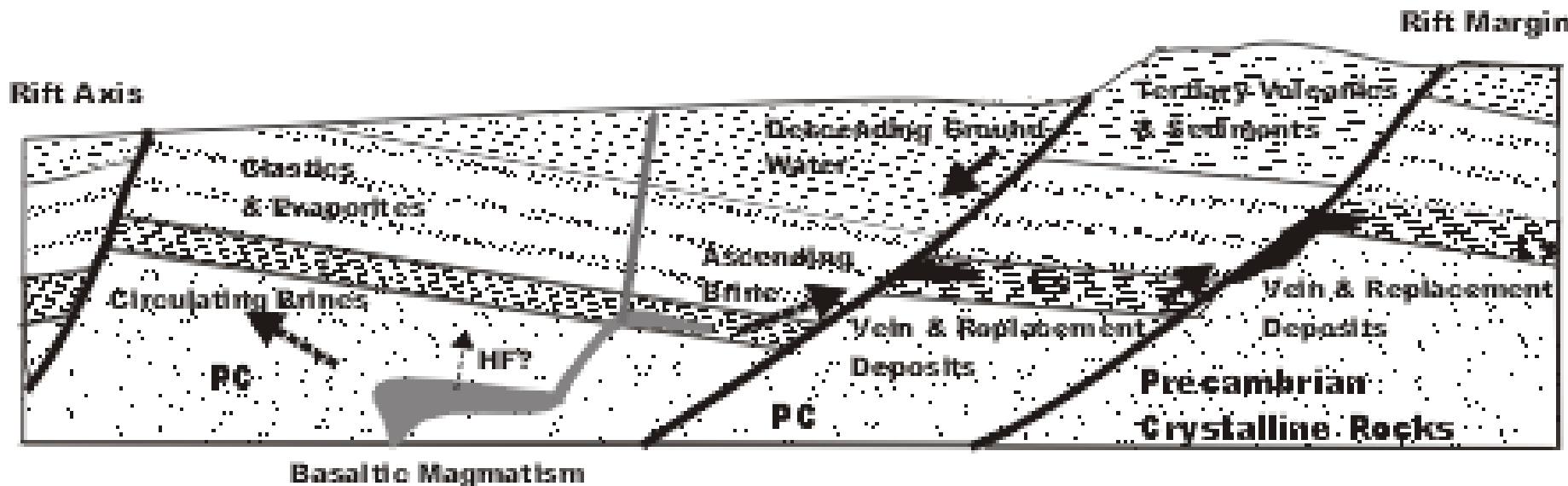


Beach placer sandstone deposits are tabular, stratabound REE-Ti-Nb-Zr-Th (U) deposits.

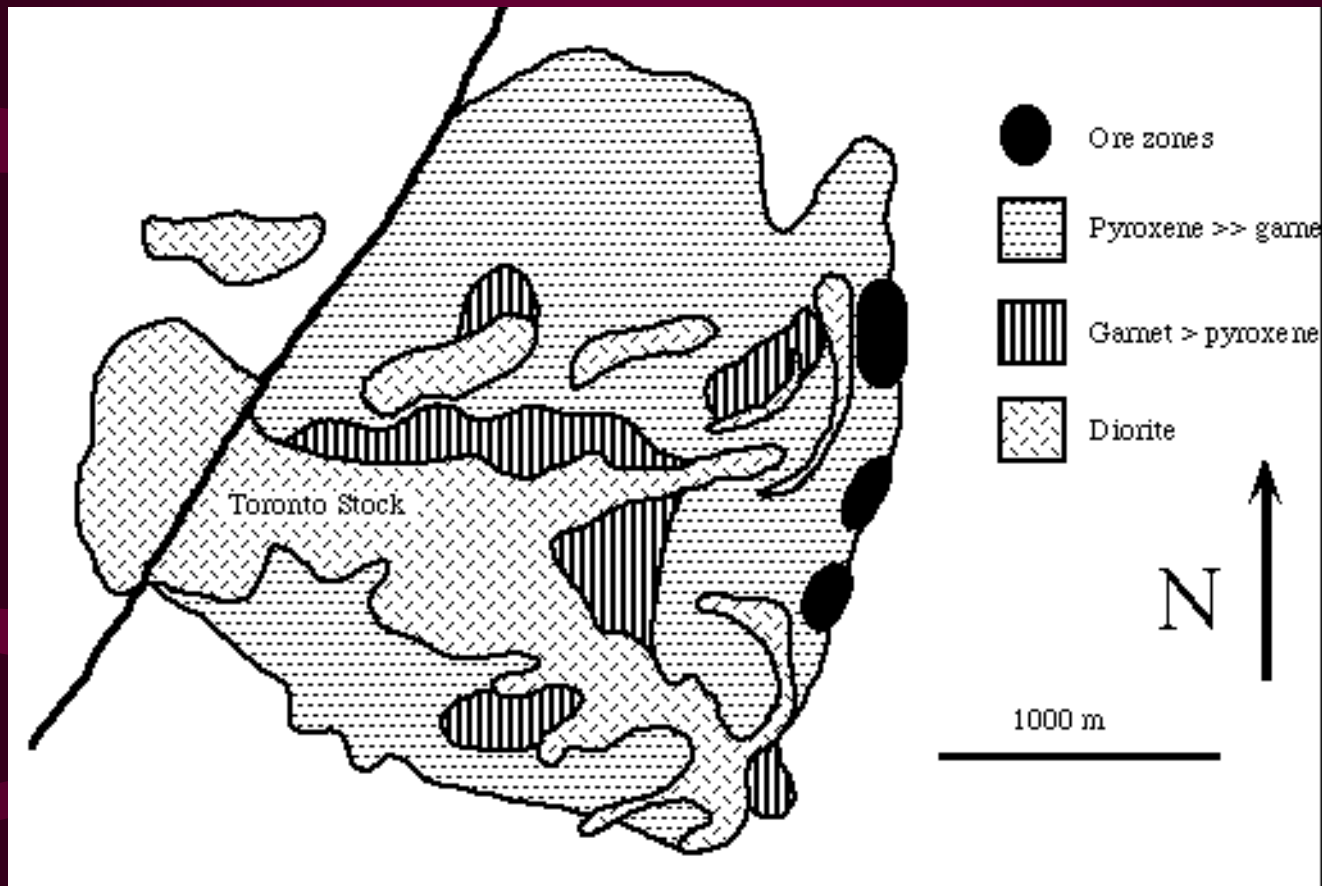


Residual mineral deposits formed by  
weathering reactions at the earth's  
surface--bauxite from Australia



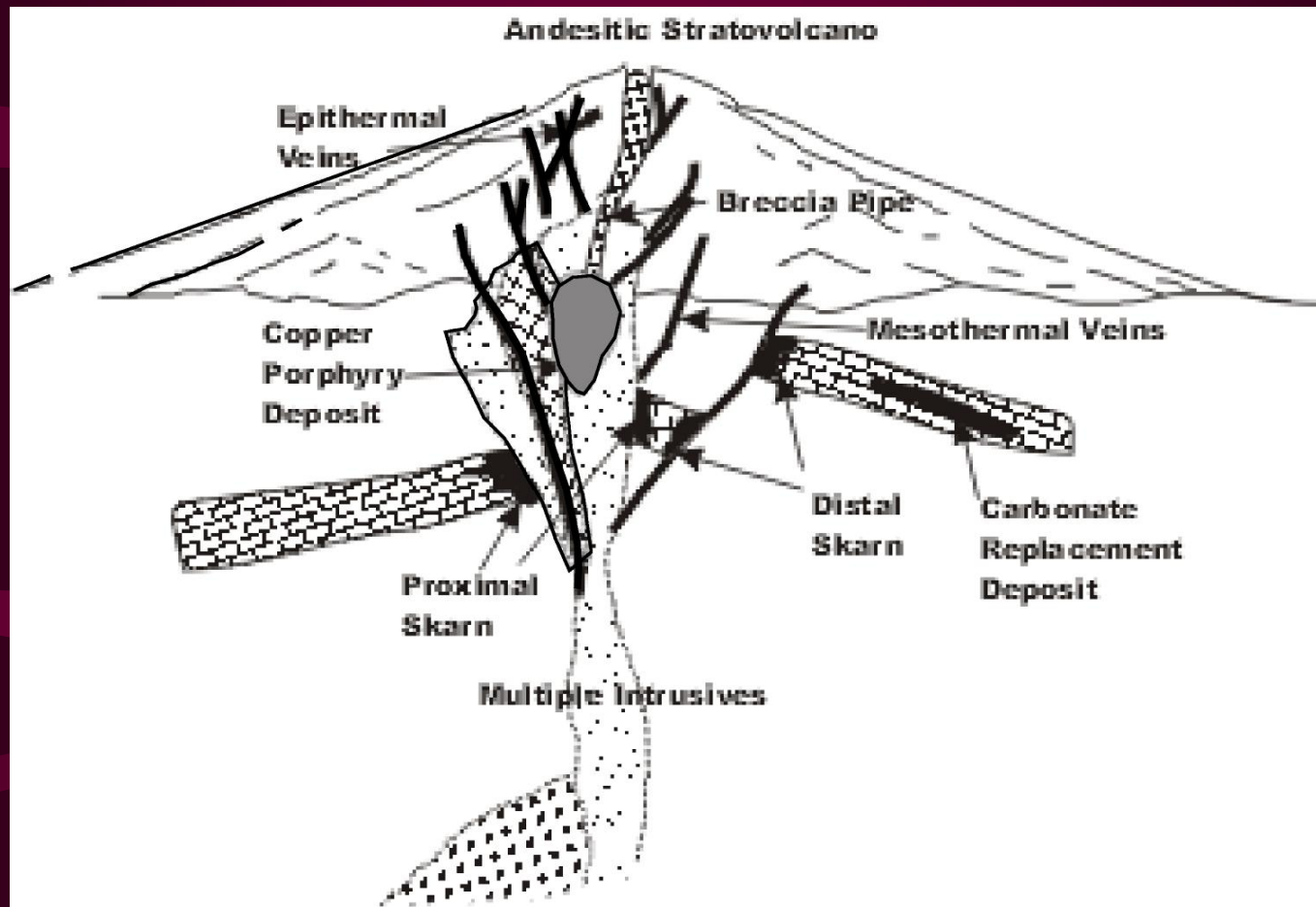


Lateral secretion or diffusion of minerals from country rocks into faults and other structures

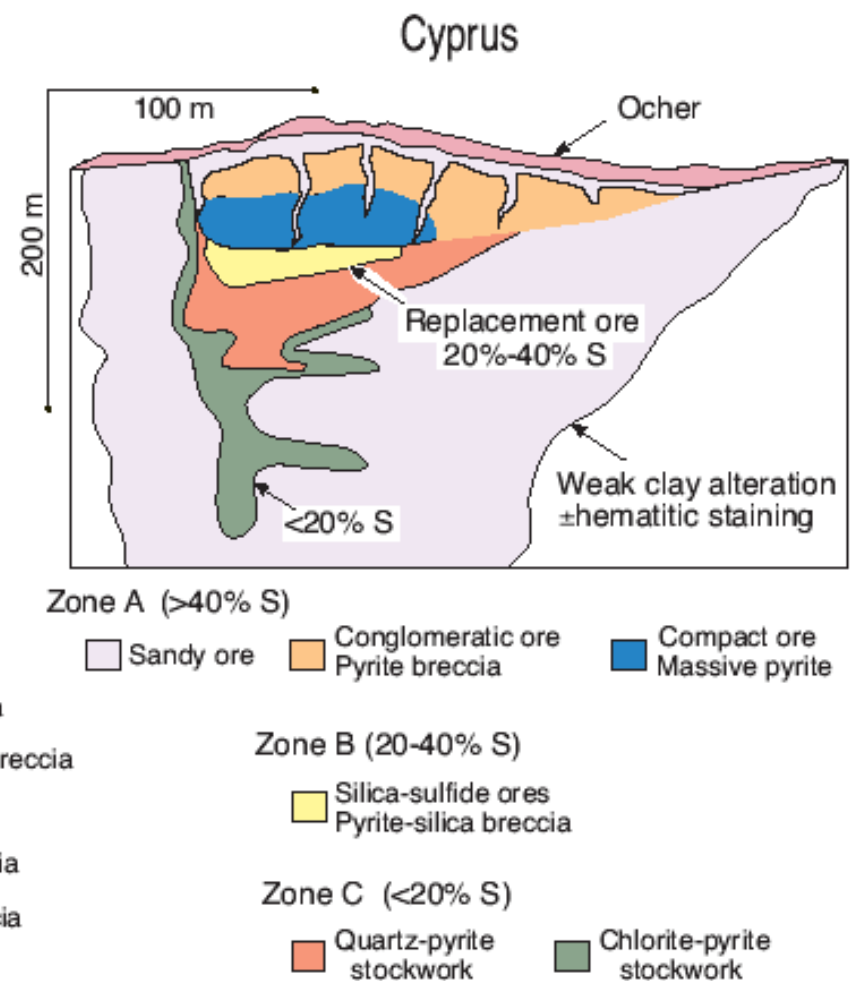
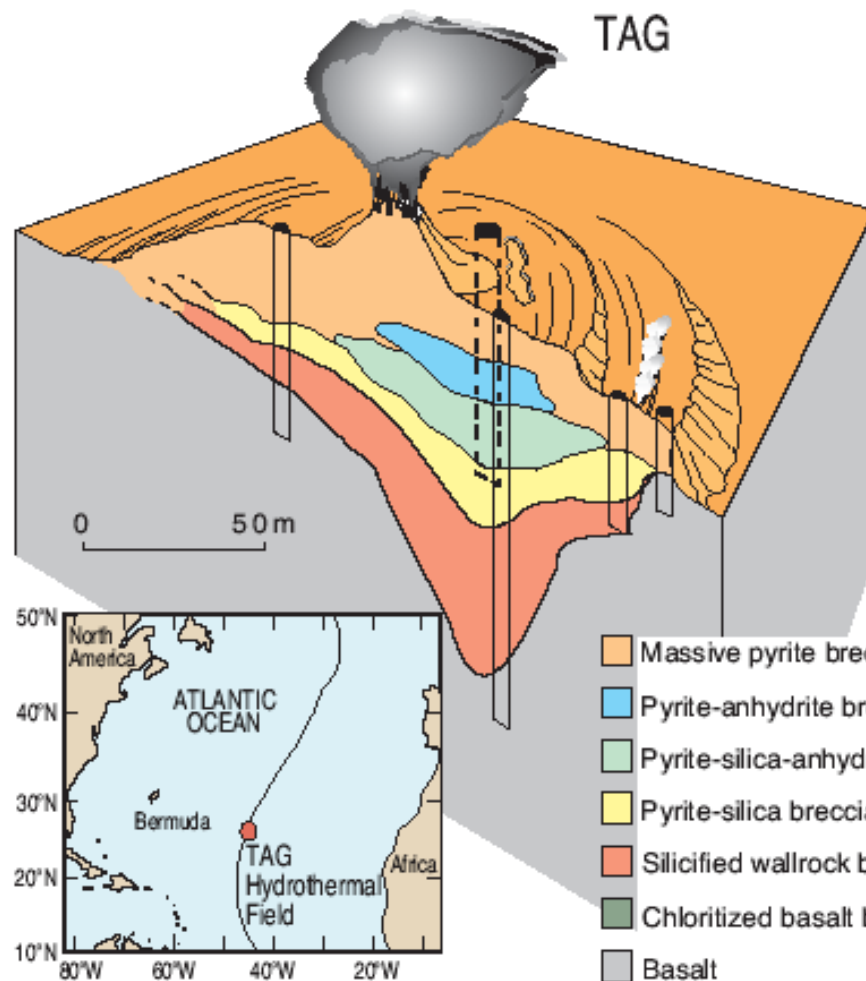


# Metamorphic processes, both contact and regional Skarns

<http://www.wsu.edu:8080/~meinert/Hedley.gif>

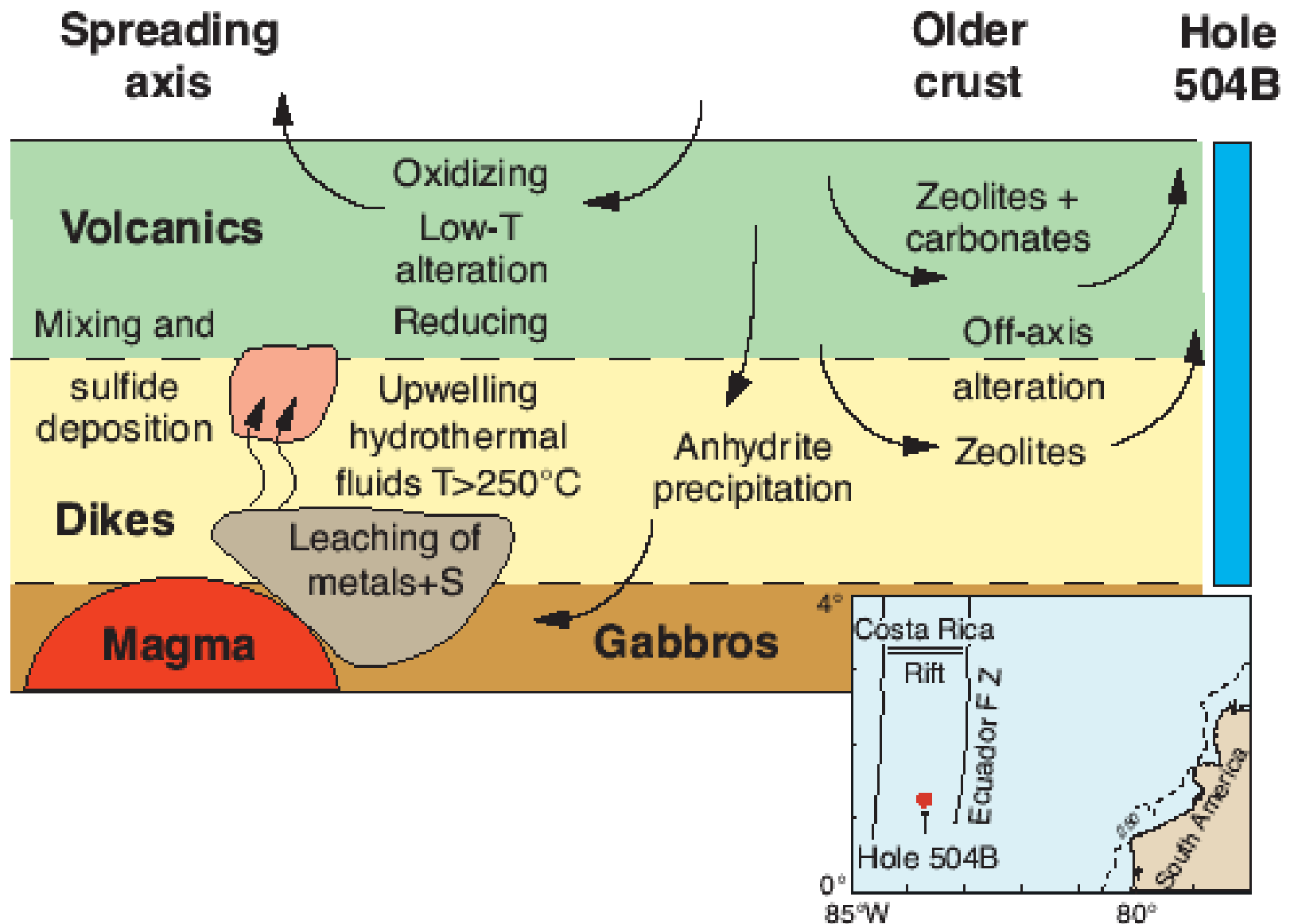


Secondary or supergene enrichment where leaching of materials occurs and precipitation at depth produces higher concentrations



# Volcanic massive sulfide deposits

[http://joides.rsmas.miami.edu/files/AandO/Humphris\\_ODPLegacy.pdf](http://joides.rsmas.miami.edu/files/AandO/Humphris_ODPLegacy.pdf)



# Shape of ore deposits

- Tabular
- Tubular
- Disseminated
- Irregular replacement
- Stratabound
- Open-space filling

# **GEOENVIRONMENTAL MODELS (GEMs)**



Geoenvironmental models  
(GEMs) were developed by the  
USGS to aid in environmental  
assessment of mineral deposits



U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Preliminary compilation of  
descriptive geoenvironmental mineral deposit models

Edward A. du Bray<sup>1</sup>, Editor

Open-File Report 95-831

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

<sup>1</sup>Denver, Colorado

1995



**Progress on Geoenvironmental Models for Selected Mineral Deposit  
Types**

Robert R. Seal II<sup>1</sup> and Nora K. Foley<sup>1</sup>  
Editors

U. S. Geological Survey Open-File Report 02-195

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<sup>1</sup> U. S. Geological Survey, 954 National Center, Reston, VA 20192

U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

**GEOENVIRONMENTAL MODELS OF MINERAL DEPOSITS,  
AND GEOLOGY-BASED MINERAL-ENVIRONMENTAL ASSESSMENTS  
OF PUBLIC LANDS**

By

Geoffrey S. Plumlee\*, Kathleen S. Smith\*, and Walter H. Ficklin\*\*

Open-File Report 94-203

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

1994

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\*\*Deceased

# DEFINITION OF GEOENVIRONMENTAL MODELS (GEMs)

“a compilation of geologic, geophysical, hydrologic, and engineering information pertaining to the environmental behavior of geologically similar mineral deposits (1) prior to mining, and (2) resulting from mining, mineral processing and smelting.”  
(Seal et al., 2002)

# KEY ELEMENTS OF GEMS

- deposit type
- deposit size
- host rock
- wall-rock alteration
- mining and ore processing method
- deposit trace element geochemistry
- primary and secondary mineralogy
- topography and physiography
- Hydrology
- climatic effects

# CAUTION

GEMs should not be used to predict absolute pH or metal concentrations that will develop at a site or in lieu of site characterization (Plumlee, 1999)

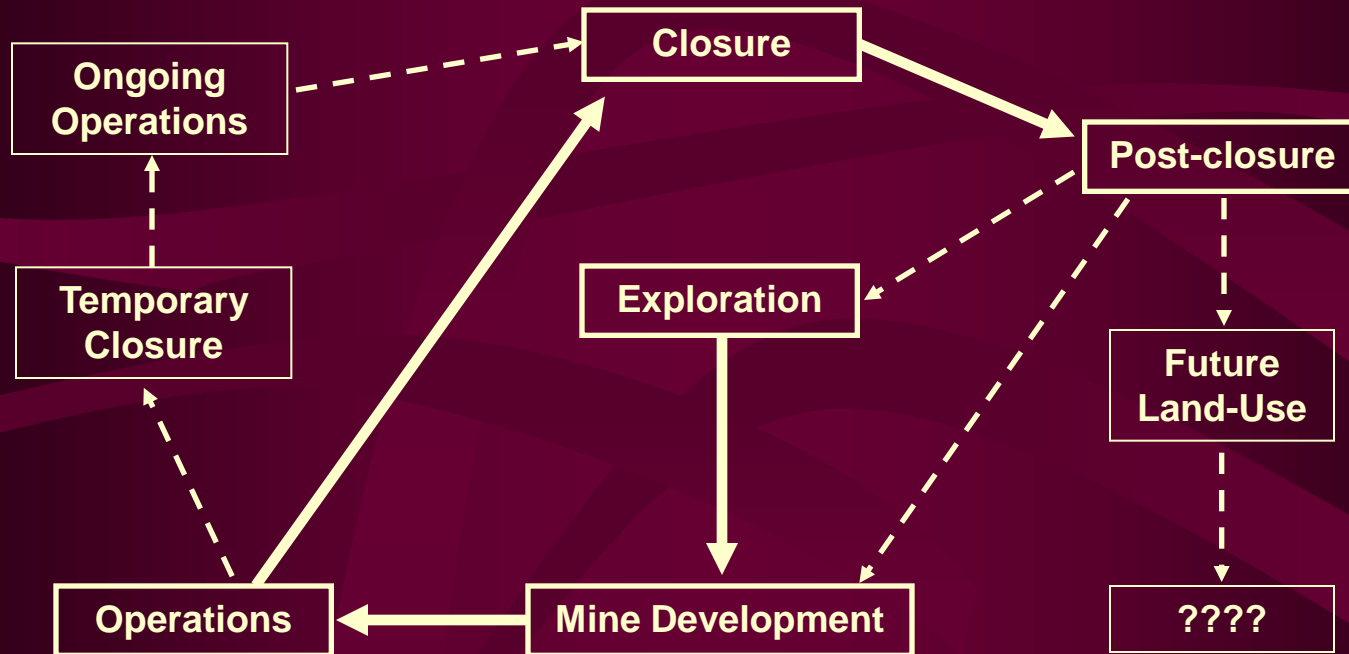
# GEMs can support and inform

- Establishment of pre-mining baseline or background conditions
- Exploration for new mineral deposits
- Mine planning and mine development
- Remediation
- Legacy issues (abandoned, inactive, historic mines)

# GEMs can support and inform— continued

- Natural altered areas that could be contributing to adverse environmental effects
- Permitting, especially in the case of new districts or the first introduction of modern mining methods
- Rational assessments of operational and closure costs

# GEMs can and should be used throughout the mine life cycle



—————> Mine Life Cycle

- - - - -> Alternative Stages



# Challenges

- Complexity of applying the GEMs
- Constraints due to project timing
- Unavailability of original exploration geologists and geochemists who have examined the deposit and adjacent areas in detail
- Communication barriers between the various teams developing the mine site.

# EXPLORATION AND FEASIBILITY STUDIES

- A means to anticipate geochemical environmental problems before they occur and aid in identifying the pre-mining baseline and background conditions
- GEMs can highlight and prioritize the types of environmental problems that could be encountered with the particular deposit type (i.e., acid drainage, presence of heavy metals, among others)

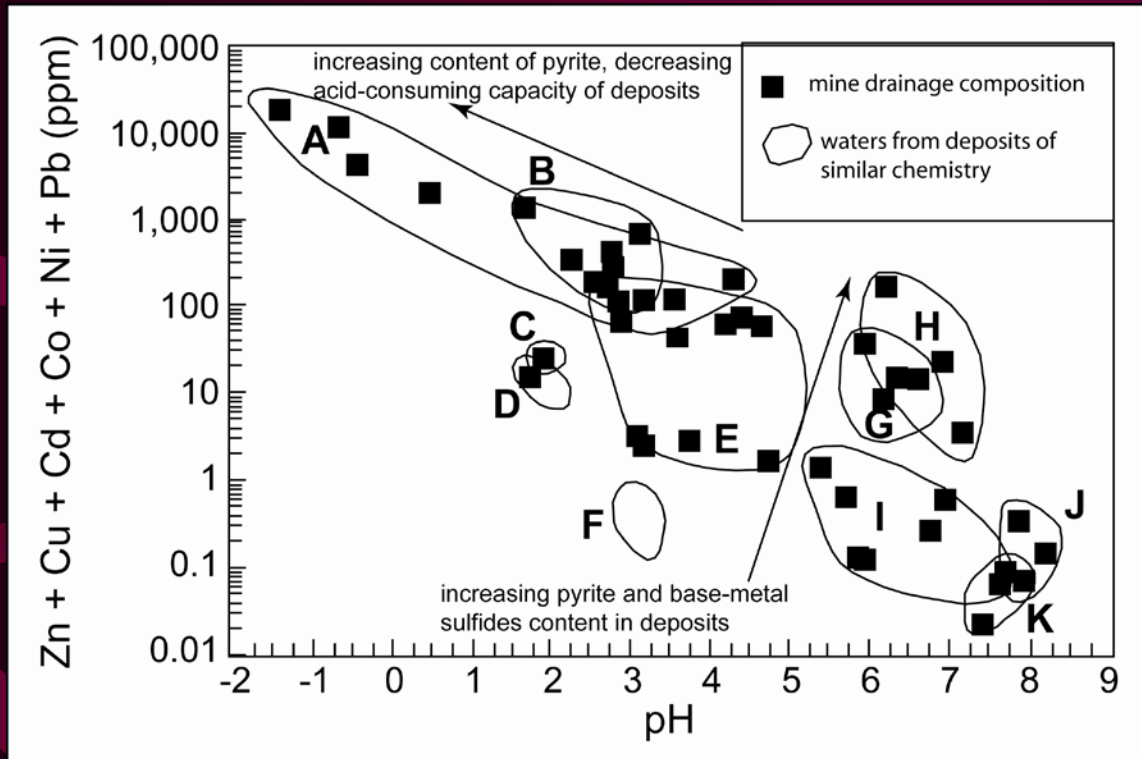
# DEVELOPMENT AND PRODUCTION STAGE

- Aid in identification of potential problems associated with specific mining methods and processing methods
- Close interactions between the metallurgists and environmental geologists/geochemists/hydrologists is essential in understanding the subtle details of the metallurgical or beneficiation process being used and how to handle the resulting wastes efficiently with minimal effect to the environment

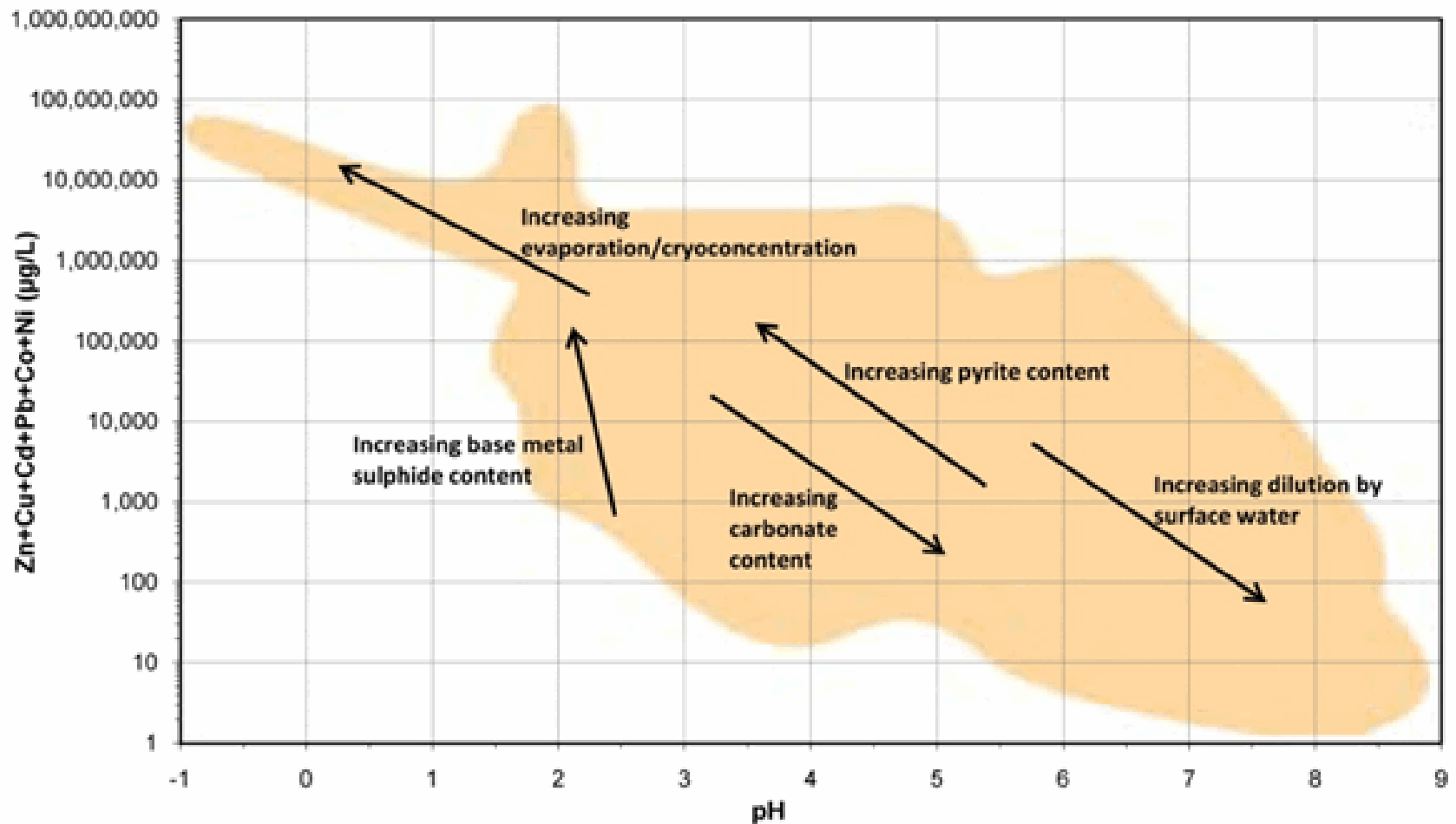
# MINE CLOSURE

- Provides a global perspective on pre-mining baseline or background conditions of similar deposit types, which are useful in establishing realistic closure goals
- Applying GEMs throughout the mine life cycle can provide a reality check, but GEMs only provide guidance and should not blind the user to new and possible contradictory information

# FICKLIN PLOT



A=pyrite-rich massive sulfides, B=sulfide-rich ores with pyrite in altered wallrock, C=high sulfide, low base-metal hot spring ores in altered wallrock, D=high-sulfide, low-base metal porphyry Mo ores, E=pyrite- and base-metal-rich polymetallic veins and disseminations in wallrock with low acid-buffering capacity, F=pyrite-rich, base metal-poor veins and disseminations in wallrock with low acid-buffering capacity, G=pyrite- and base metal-rich polymetallic veins with carbonate or in carbonate wallrock, H=pyrite- and base metal-rich, polymetallic replacements and veins in carbonate-rich sediments, I=polymetallic veins with moderate to low pyrite and base metal content that are carbonate-rich or in carbonate wallrock, J=pyrite-poor polymetallic replacements in carbonate-rich sediments, K=pyrite-poor, Au-Te veins and breccias with carbonate gangue.



Arrows show likely path of water chemistry as a result of designated chemical processes (Revised from Ficklin, 1992; Plumlee et al., 1999; INAP, 2010)

# Examples of the Use of Gems at Mine Sites

Observed environmental issues  
that are consistent with GEM-  
predicted issues at selected mines  
and deposits



- Kuipers and others released a study examined the performance of reclamation of major mines on U.S. federal land that were required to submit EA or EIS recognize that geologic
- Geochemical and hydrologic characteristics are important in understanding water quality issues at mine sites and not all sites included detailed geologic descriptions
- 11 of their 25 mines selected as case studies exhibited inadequacies in geochemical characterization of the sites

Kuipers, J.R., Maest, A.S., MacHardy, K.A.,  
and Lawson, G., 2006, Comparison of  
predicted and actual water quality at hardrock  
mines: the reliability of predictions in  
Environmental Impact Statements: Kuipers  
and Associates and Buka Environmental, 228  
p.,  
<http://www.earthworksaction.org/pubs/ComparisonsReportFinal.pdf>

# **Red Mountain, Alaska (VMS, base and precious metals)**

Presence of pyrite weathering has produced acid generation, high metal and REE content in surface waters. This deposit has not yet been mined.

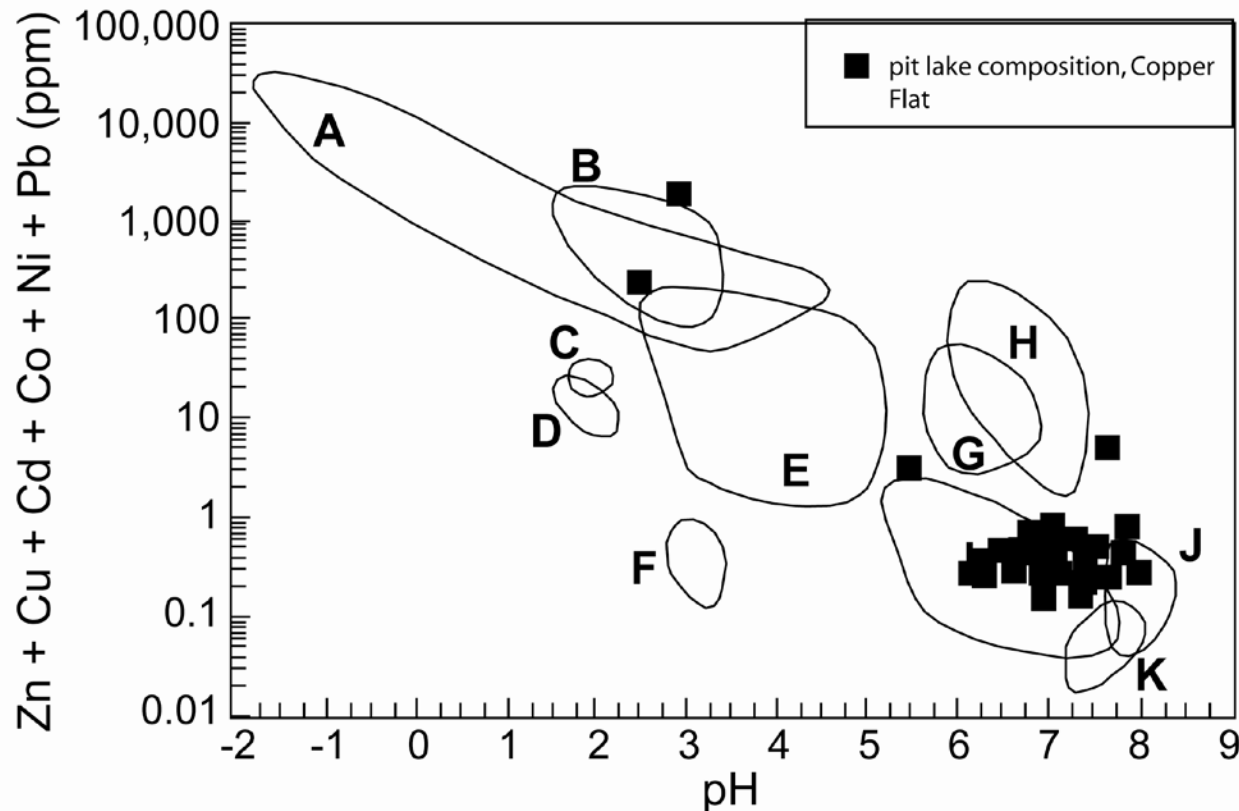
# Questa Climax molybdenum mine, New Mexico

Acid drainage in surface and ground water from waste rock piles and tailings contains high metal content (Cd, As, Pb, Sb), F, and sulfate. Altered areas upstream of mine also contribute high metals, F, and acid drainage. Carbonate is present in some rock piles and neutralizes acid drainage locally.

# Copper Flat porphyry copper deposit at Hillsboro, NM

- pH of the lake is typically neutral to alkaline, with exception occurring in 1992 and 1993, where the pH dropped as low as 4.4
- Water samples from the porphyry copper deposit are near-neutral, low metal waters, although a few pit lake samples are high metal, acid waters

# Copper Flat porphyry copper deposit at Hillsboro, NM



I=polymetallic veins with moderate to low pyrite and base metal content that are carbonate-rich or in carbonate wallrock, J=pyrite-poor polymetallic replacements in carbonate-rich sediments

# FINAL COMMENTS

- If the GEM had been available and applied in some of these sites, some of the environmental issues could have been predicted and planned for
- GEMs provide a first-order means of predicting environmental issues at mines
- More research is needed in the application of GEMs

# FIELD NOTES

1962-1963

1964-1965

1966-1967

1968-1969

1970-1971

1972-1973

1974-1975

1976-1977

1978-1979

1980-1981

1982-1983

1984-1985

1986-1987

1988-1989

1990-1991

1992-1993



# Field Notes

- Not writing down your observations could result in missed data being recorded and lead to inaccurate conclusions about the rocks being studied.
- Field notes allow you to write down descriptions of fossils, minerals, or rocks while they are being collected. This saves time
- Sketches are also helpful in interpreting geologic events.
- Field notes can be a legal document, and must be saved for future reference.

# Field Notes

- Record date, time, location, who, weather
- Describe locality
- Sketch
- Photographs
  - Location
  - Direction
  - Description
- Other notes, comments, future work

# Field Notes

- If you are unsure of the name of a rock, fossil, or mineral, make a description of it, but do not name it until you can confirm its identity.
- Detailed description
  - thickness of the beds
  - describe the rocks
  - record any fossils or minerals
  - Strike and dip, trend
  - unique features (layered, cross-bedding, ripple marks)

# Field Notes

- Collect samples
  - Date
  - Location
  - Photograph
  - Description
  - Lithology
  - Unit if known
  - Purpose of sampling

# SAMPLING

# WHY SAMPLE

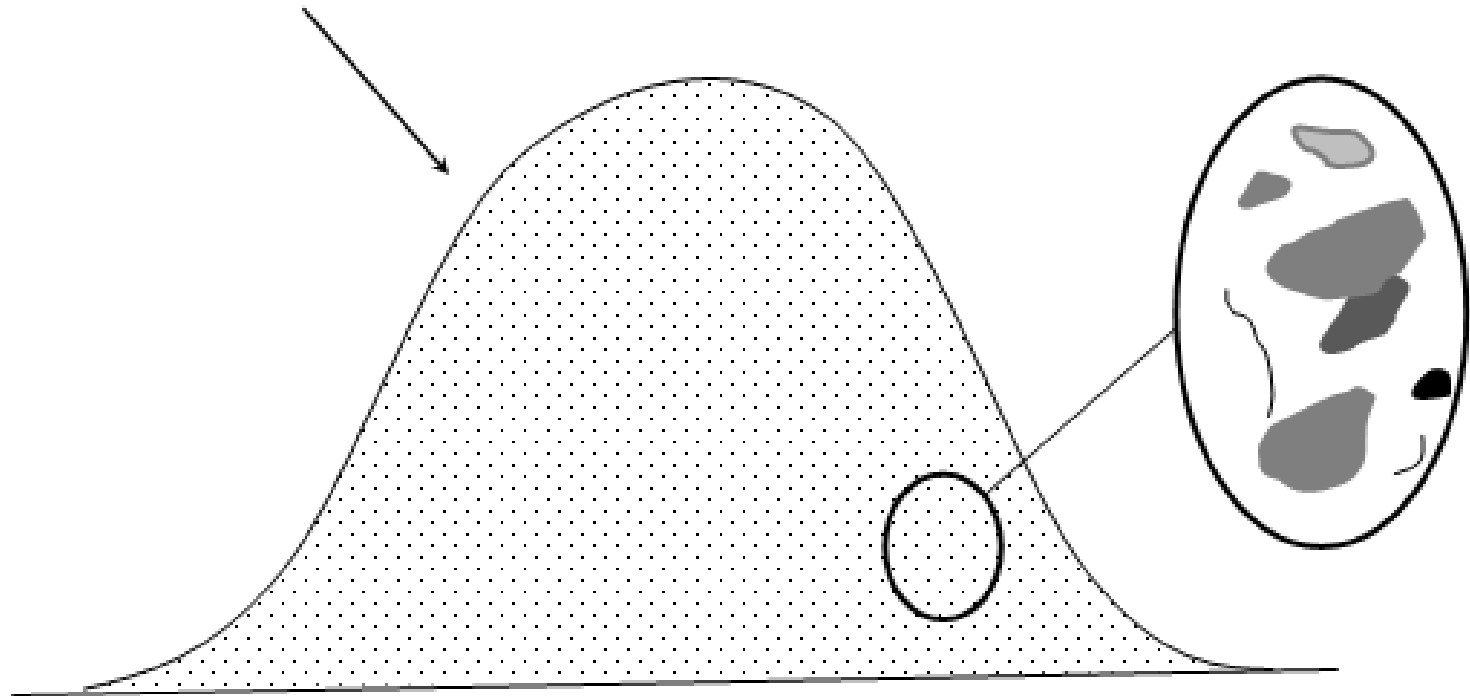
- Exploration stage to locate economic mineral deposits, drill targets.
- Development stage to determine reserves.
- Production stage to maintain grade control.
- Environmental monitoring, compliance.

# SAMPLING MEDIA

A variety of sampling media can be tested

- solid
- liquid
- air
- biological

## “Homogeneous” Pile of Sand



Heterogeneity as a function of the scale of observation (from McLemore et al., 2014)



# COMPONENTS OF A SAMPLING PLAN

- Define questions and objectives
- Develop site conceptual models
- Costs and potential consequences of not sampling
- Identify types of data and information needed
- Define confidence level and quantity of data required to answer questions
- Design the sampling plan

# COMPONENTS—continued

- Develop protocols
- Conduct an orientation or pilot study before implementation
- Conduct sampling plan
- Analyze and manage data (interpretation)
- Make decisions (risk management)
- Educate and inform the parties involved

# 1. DEFINE QUESTIONS AND OBJECTIVES

- Identify sources, transport, and effects of potential contamination of soil and drainage quality.
- Validate predicative models.
- Validate mitigation/remediation/reclamation efforts.
- Preventative and remediation monitoring.
- Establish background or existing conditions.
- Identify impacted areas vs. pristine areas.
- Potential use of water in operations
- Operational compliance monitoring.
- Validate reclamation efforts

## 2. DEVELOP SITE CONCEPTUAL MODELS

### **Review existing data**

- Climatic data
- Physical data
- Geology (mineralogy)
- Hydrogeology (Surface-ground water interaction)
- Mining history and impacts of mine workings
- Biology
- Other data available

### 3. COSTS AND POTENTIAL CONSEQUENCES OF NOT SAMPLING

- Avoid being data rich but information poor.
- Public perceptions of risk.
- Perceptions of chemicals associated with the mining industry, such as cyanide.
- Some long-term and widespread environmental problems should be considered relatively high-risk even if the data on which the risk assessment is based are somewhat incomplete and uncertain.

## **4. IDENTIFY TYPES OF DATA AND INFORMATION NEEDED**

- What sampling media (solid, liquid, biological/wetlands, air)?
- What are sources, transport mechanisms, and receptors?
- What other parameters must be monitored?
- What type of sample is to be collected and is it representative of sampling?
- What field measurements are required?
- What is the feasibility of sampling?

## **5. DEFINE CONFIDENCE LEVEL AND QUANTITY OF DATA REQUIRED TO ANSWER QUESTIONS**

- What is the confidence level needed?
- How many samples are required to get the needed results?
- What is the precision required?

## 6. DESIGN THE SAMPLING PLAN

- QA/QC
- Data format
- Safety issues (OSHA vs. MSHA vs. local, state vs. good neighbor/employer)
- Sample location, number of samples, and frequency of sampling, proper labeling of samples (site specific)
- What constituents or parameters are required for each media



## 7. DEVELOP PROTOCOLS

- Collection techniques
- Sample collection
- Observational field data
- Modify sampling plan and deviations
- Opportunistic sampling
- Contamination
- Handling/transport
- Preservation and storage (from field to laboratory)

## 7. DEVELOP PROTOCOLS—continued

- Sample pre-treatment in the laboratory
- Filtration
- Sample preparation
- Sample separation
- Archival/storage
- Analytical procedures and techniques

## 8. ORIENTATION OR PILOT STUDY

- Clear understanding of target type
- Understanding of surficial environments
- Nature of dispersion from mineralized areas
- Sample types available
- Sample collection procedures
- Sample size requirements

## 8. ORIENTATION OR PILOT STUDY

- Sample interval, depth, orientation, and density
- Field observations required
- Sample preparation procedures
- Sample fraction for analyses
- Geochemical suite for analyses
- Data format for interpretation

# **9. CONDUCT SAMPLING PLAN (PROGRAM IMPLEMENTATION)**

# 10. ANALYZE AND MANAGE DATA

- Reporting data
- Presentation of data
- Interpretation
- Data interpretation approaches
  - Statistical
  - Spatial
  - Geochemical
  - Geological

## **10. ANALYZE AND MANAGE DATA— continued**

- Reporting and dissemination
- What becomes of data (storage)
- Common data formats
- Use the data
- Reliability and limitations of findings
- Evaluate the data (statistics)

# **11. MAKE DECISIONS (RISK MANAGEMENT)**



## **12. Educate and inform the parties involved**

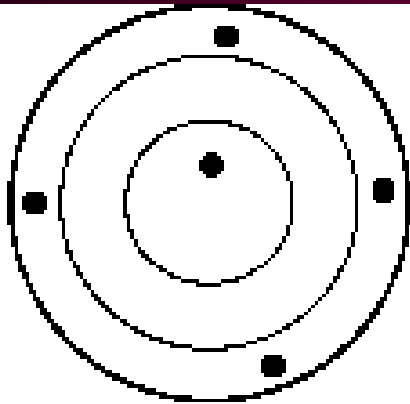
# DATA VERIFICATION

**“All analytical measurements are wrong: it’s just a question of how large the errors are, and whether they are acceptable”  
(Thompson, 1989).**

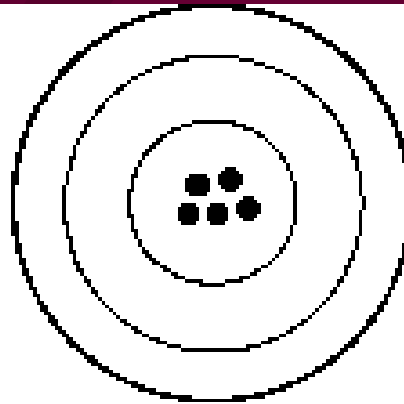
# DEFINITIONS

- ***Precision*** -- the degree of agreement among repeated measurements of the same characteristic. Precision is monitored by multiple analyses of many sample duplicates and internal standards.
- ***Accuracy*** -- measures how close your results are to a *true* or expected value and can be determined by comparing your analysis of a standard or reference sample to its actual value. Analyzing certified standards as unknown samples and comparing with known certified values monitors accuracy.
- ***Completeness*** -- the comparison between the amount of valid, or usable, data you originally planned to collect, versus how much you collected.
- ***Comparability*** -- the extent to which data can be compared between sample locations or periods of time within a project, or between projects.

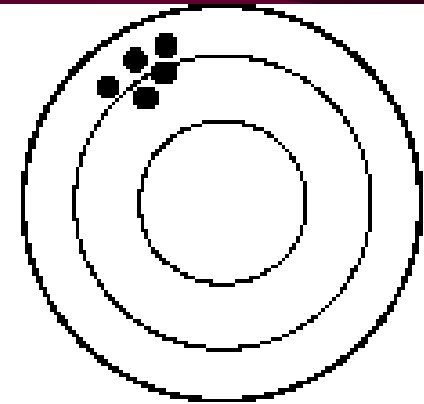
# The difference between precision and accuracy



POOR PRECISION  
(RANDOM BIAS)



PRECISE  
AND  
ACCURATE



PRECISE,  
BUT NOT  
ACCURATE  
(SYSTEMATIC  
BIAS)

# **QUALITY CONTROL/QUALITY ASSURANCE**

- **QC is referred to a program designed to detect and measure the error associated with a measurement process. QC is the program that ensures that the data are acceptable.**
- **QA is the program designed to verify the acceptability of the data using the data obtained from the QC program. QA provides the assurance that the data meets certain quality requirements with a specified level of confidence.**

# QUALITY CONTROL/QUALITY ASSURANCE

- What is the purpose of your project?
- What do you need the analyses for and how accurate should they be?
- Where are the results going to be released or published?
- What is the mineralogy?
- What are appropriate certified standards (may need to develop lab standards)?
- What are the detection limits (both upper and lower)?
  - Analytical errors vary from element to element, for different ranges of concentration, and different methods
- Duplicate or more analyses of standards and unknowns verses duplicate runs of same sample

# QUALITY CONTROL/QUALITY ASSURANCE

- Analyze a separate set of standards rather than standards used for calibration
- Send samples and standards to other laboratories
- Establish written lab procedures
- Are blanks and field blanks used and analyzed?
- What are the custody procedures (collection date, preservation method, matrix, analytical procedures)?
- Does the chemical analyses make geological sense? Is it consistent with the mineralogy and type of mineral deposit?
- Sometimes there is more paper work than making sure the data is accurate
- What do you do if there are problems with QA/QC?

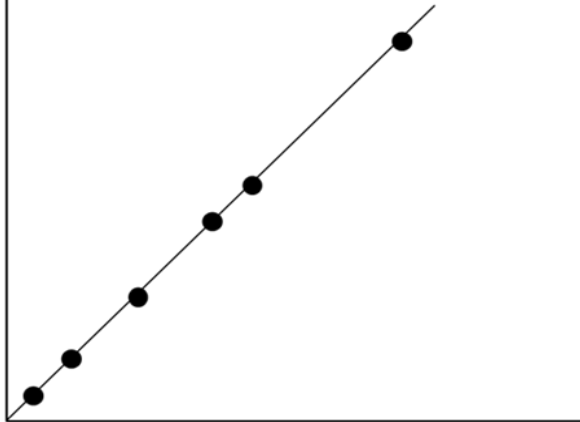


# TYPES OF ERRORS

- Systematic versus bias (constant, unintentional)
- Random errors (unpredicted but nonsystematic errors, imprecise practices)
- Gross or illegitimate errors (procedural mistakes)
- Deliberate errors

True Sample Content

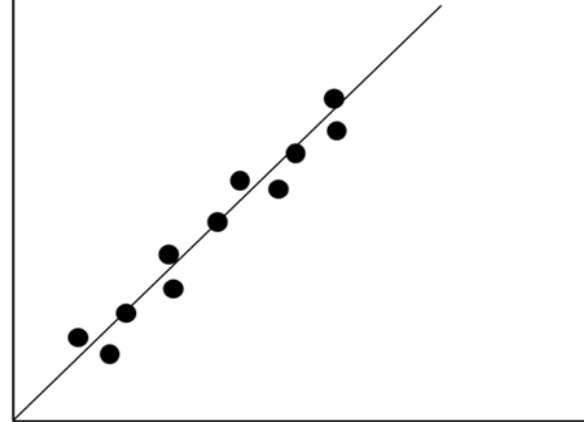
Unbiased and reproducible



True Value of Target Population

True Sample Content

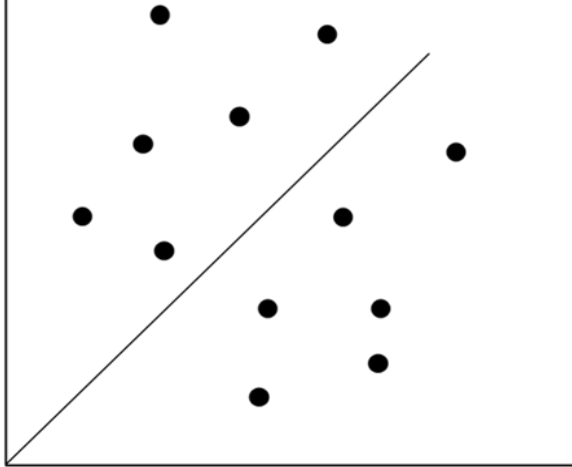
Accurate and reproducible



True Value of Target Population

True Sample Content

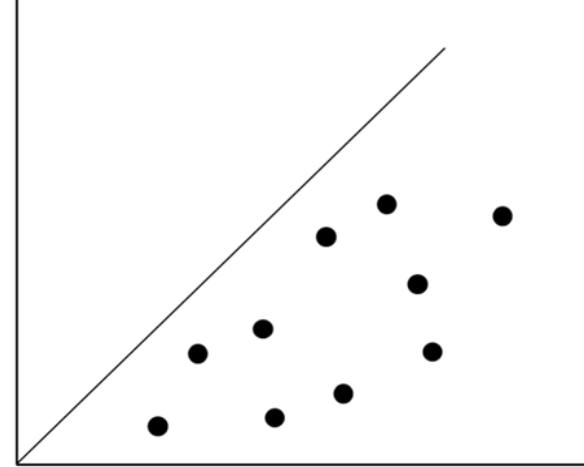
Not reproducible



True Value of Target Population

True Sample Content

Non-reproducible bias



True Value of Target Population

Reproducibility and bias in sampling (Adapted from Pitard 1993)

# MEASUREMENT ERRORS

- Wrong sample
- Wrong reading
- Transposition or transcription errors
- Wrong calibration
- Peak overlap
- Wrong method
- Contamination
- Losses
- Inattention to details
- Sampling problems
- Instrument instability
- Reagent control
- Variability of blank
- Operator skill
- Sample variability

# COMMODITIES OUTLINE

- Introduction (definition)
- Uses (properties)
- Production
- Geologic descriptions and distribution
- Processing, marketing

# ASSIGNMENT

- Bleiwas, D.I., 2010, Byproduct mineral commodities used for the production of photovoltaic cells: U.S. Geological Survey Circular 1365, 10 p., available at <http://pubs.usgs.gov/circ/1365/>.